Tu2E-2

A Compact Multi-Channel CMOS Frequency Multiplier for Millimeter-wave and Terahertz Signal Generation

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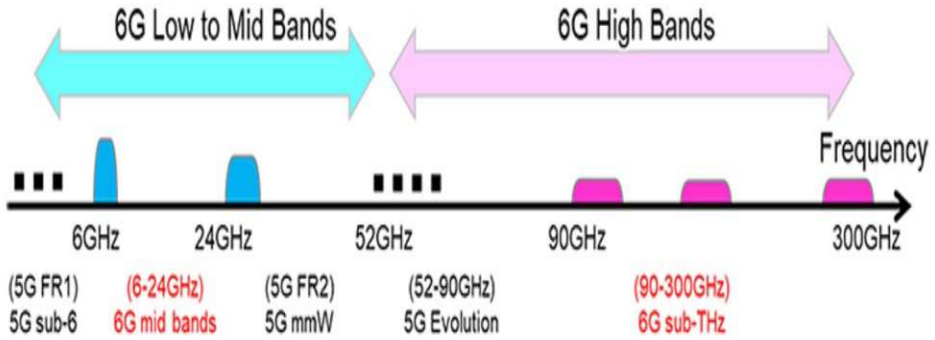
Outline

- Introduction
- Motivation
- Proposed Multi-Channel Frequency Multiplier
- Sub Building Blocks
- Measurement Results
- Summary

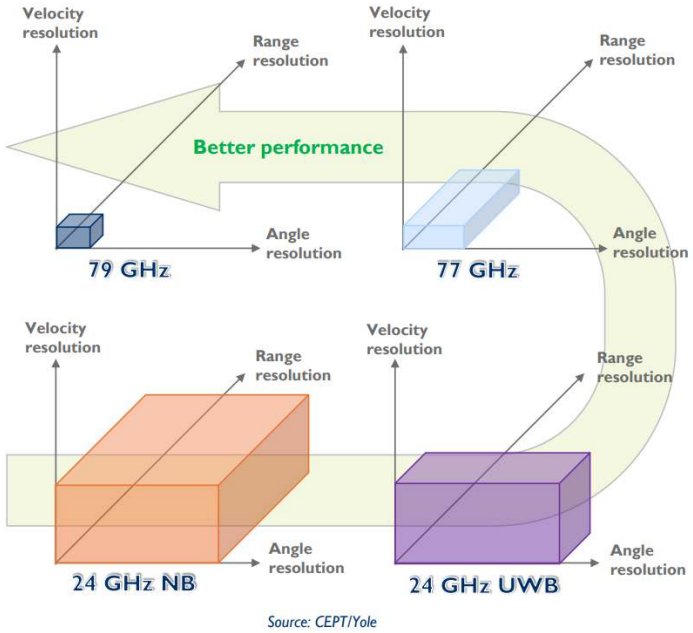
Introduction

- Millimeter-wave to Terahertz Frequency
  - 5G, B5G, and 6G
  - ISM band (60 GHz, 120GHz, 240 GHz)
  - Automotive Radar (77 GHz, 120 GHz, 140 GHz)



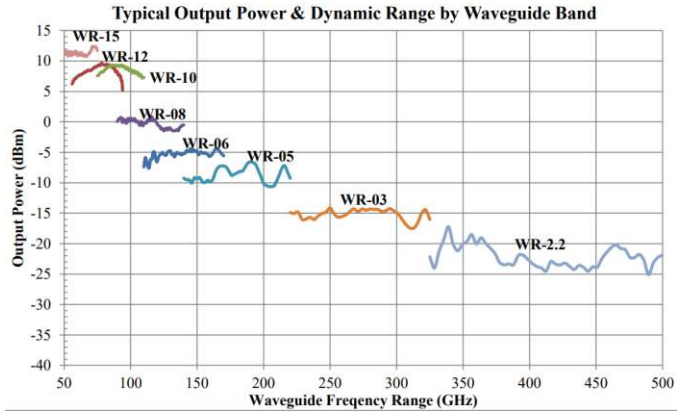
Frequency (GHz)	Bandwidth (GHz)
116~123	7
174.8 ~ 182	7.2
185 ~ 190	5
244 ~ 246	2
Total	21.2

New ISM spectrum by FCC 15.238

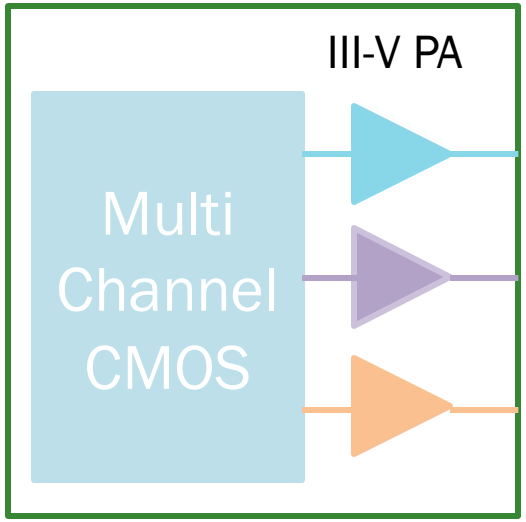


Motivation

- Commercial Active Multiplier Chains
  - Single input → Single Output for each waveguide band

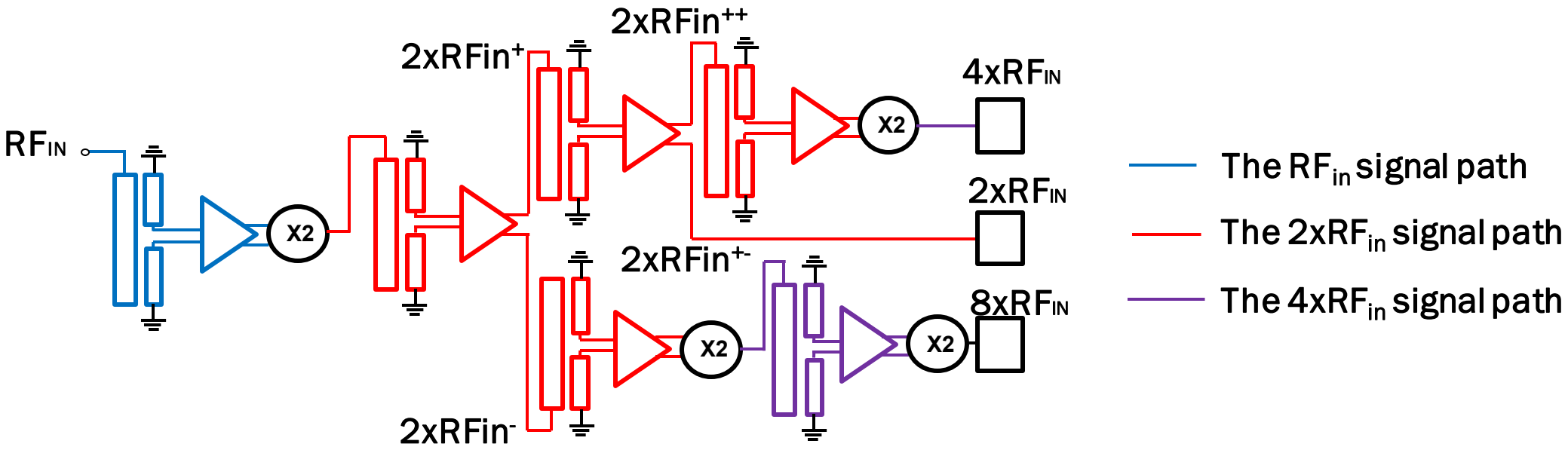


VDI AMC-I Standard Product List					
VDI Part #	Band (GHz)	Output Flange	RF Frequency Multiplication Factor	Typical Output Power (dBm)	Minimum Output Power (dBm)
WR1.0AMC-I	750 - 1,100	WM-250 (WR1.0) UG-387U-M	81	-16	-26
WR1.5AMC-I	500 - 750	WM-380 (WR1.5) UG-387/U-M	54	-7	-13
WR2.0AMC-I	400 - 550	WM-470 (WR1.9) UG-387/U-M	36	1	-5
WR2.2AMC-I	330 - 500	WM-570 (WR2.2) UG-387/U-M	36	0	-6
WR2.8AMC-I	260 - 400	WM-710 (WR2.8) UG-387/U-M	27	5	-1
WR3.0AMC-I	250 - 375	WM-710 (WR2.8) UG-387/U-M	27	5	0
WR3.4AMC-I	220 - 330	WR3.4 UG-387U-M	18	6	3
WR4.3AMC-I	170 - 260	WR4.3 UG-387/U-M	18	8	3
WR4.5AMC-I	160 - 250	WR4.3 UG-387U-M	18	10	5
WR5.1AMC-I	140 - 220	WR5.1 UG-387/U-M	12	10	6
WR6.5AMC-I	110 - 170	WR6.5 UG-387U-M	12	18	15
WR8.0AMC-I	90 - 140	WR8.0 UG-387/U-M	12	19	13
WR9.0AMC-I	82 - 125	WR9.0 UG-387U-M	9	20	17
WR10AMC-I	75 - 110	WR10 UG-387/U-M	6	20	17
WR12AMC-I	60 - 90	WR12 UG-387U-M	6	20	17
WR15AMC-I	50 - 75	WR15 UG-387/U-M	6	20	17



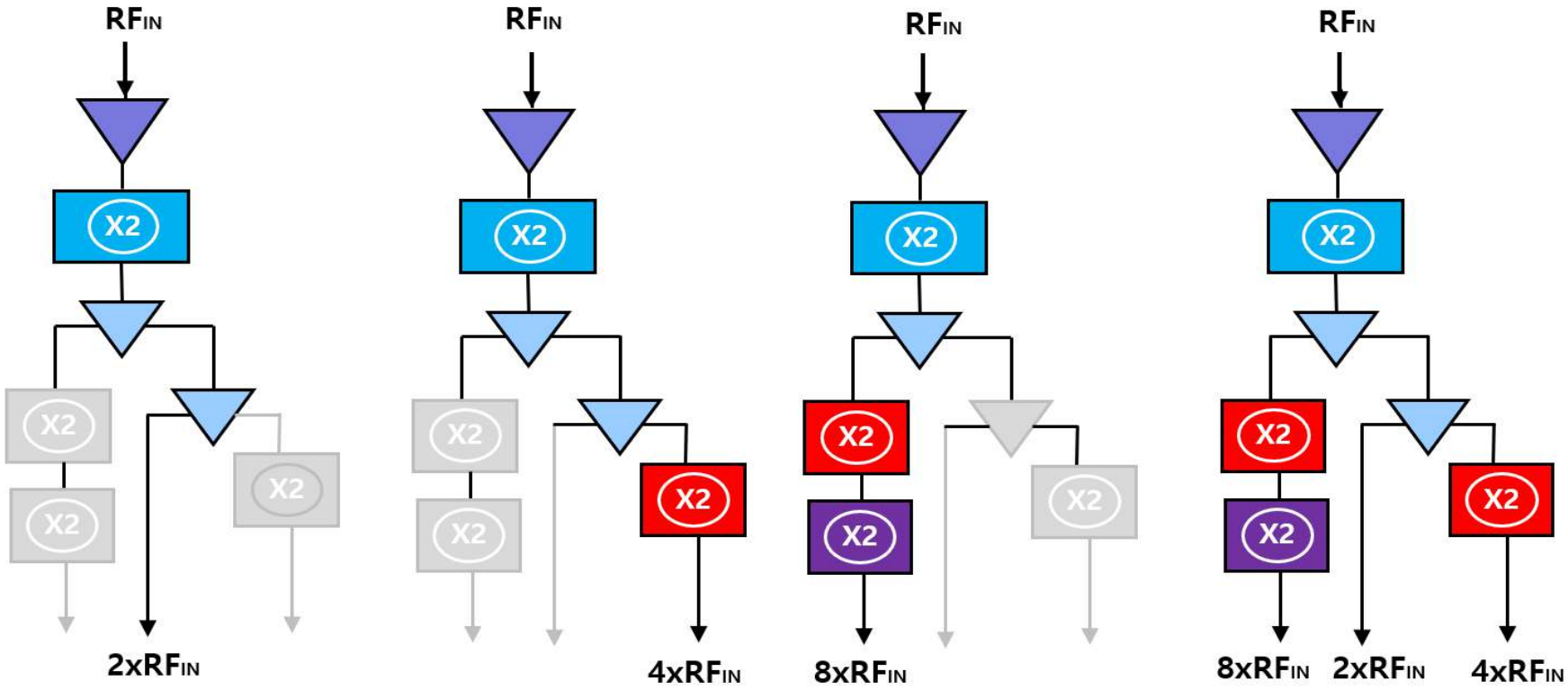
Proposed Topology

- Proposed Multi-Channel Active Frequency Multiplier
  - Each Doubler operate balanced topology
  - Need the wideband balun for each band
  - Fractional bandwidth > 20% (mostly depend on the driving amp.)



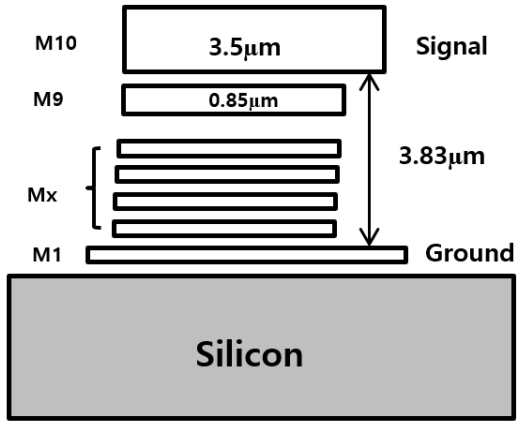
Proposed Topology – Cont.

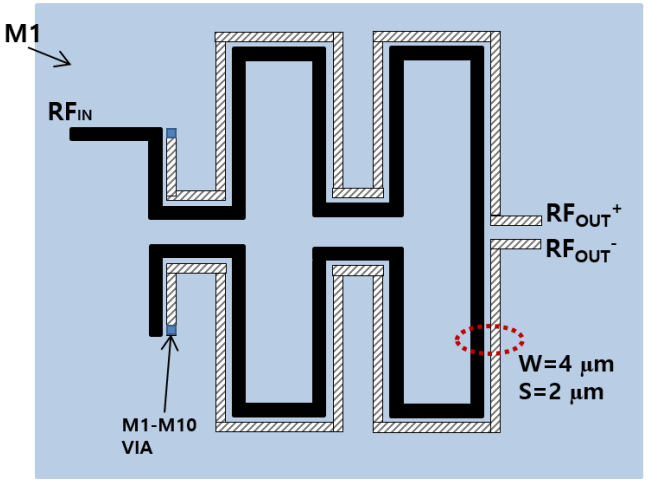
- Operating Modes (on/off control of the each drive amp.)
  - Three Independent Source Generations
  - Three Simultaneous Source Generations

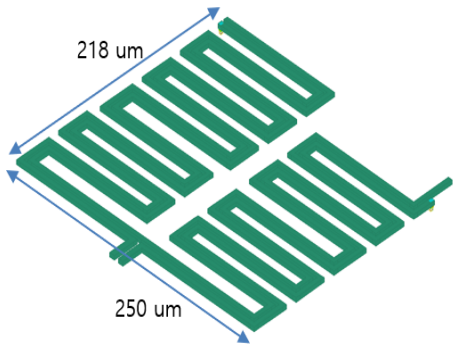


Marchand Balun

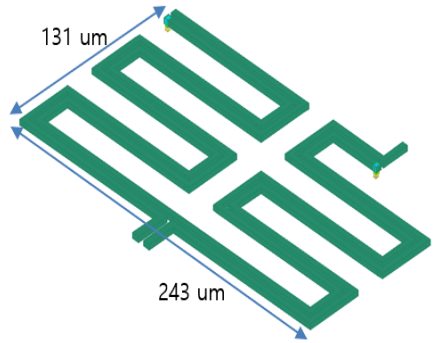
- Three Different Marchand Baluns
  - Meandered Microstrip Structure
  - Phase & Amplitude : 0.8 dB/0.8° (27~33 GHz), 0.8 dB/ 0.6° (54~66 GHz). 1.1 dB/2.4° (108~132 GHz)



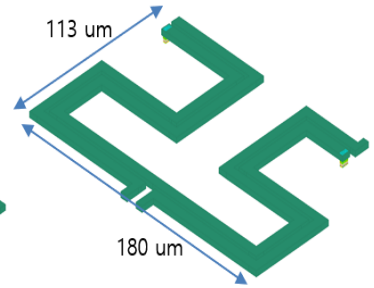




< 30GHz Marchand balun >



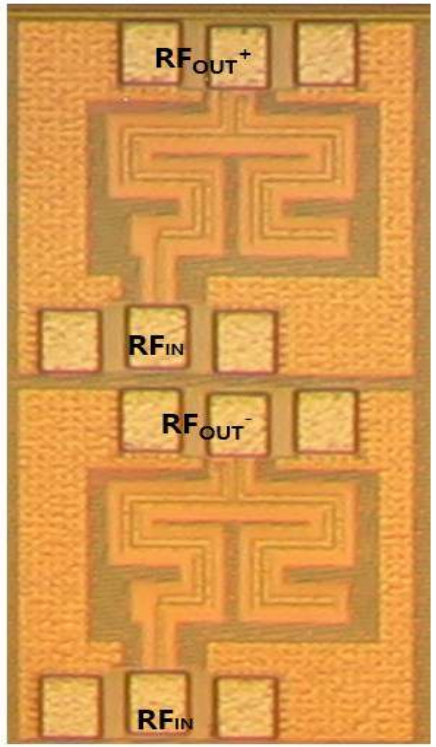
< 60GHz Marchand balun >

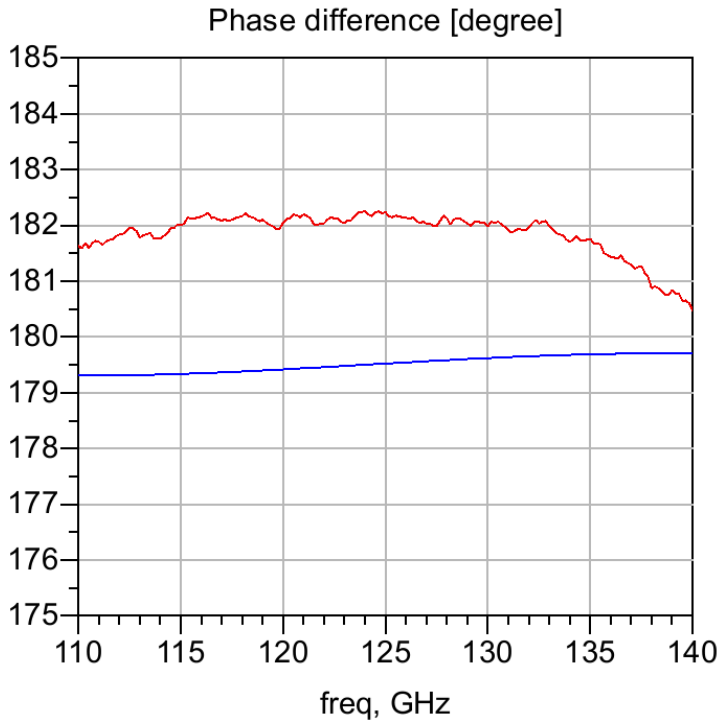


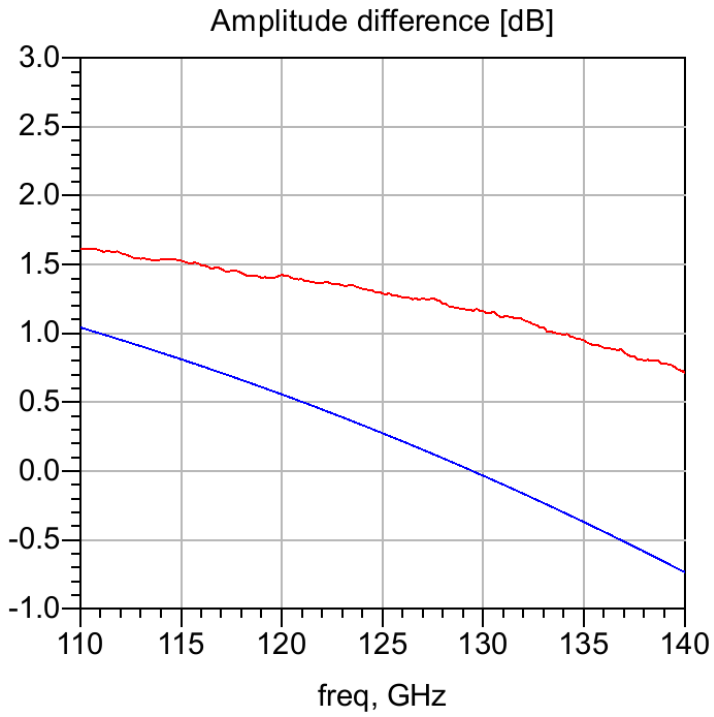
< 120GHz Marchand balun >

Marchand Balun

- 120 GHz Marchand Balun
  - Two types of test patterns
    - One of two differential outputs is terminated with 50 Ω resistor

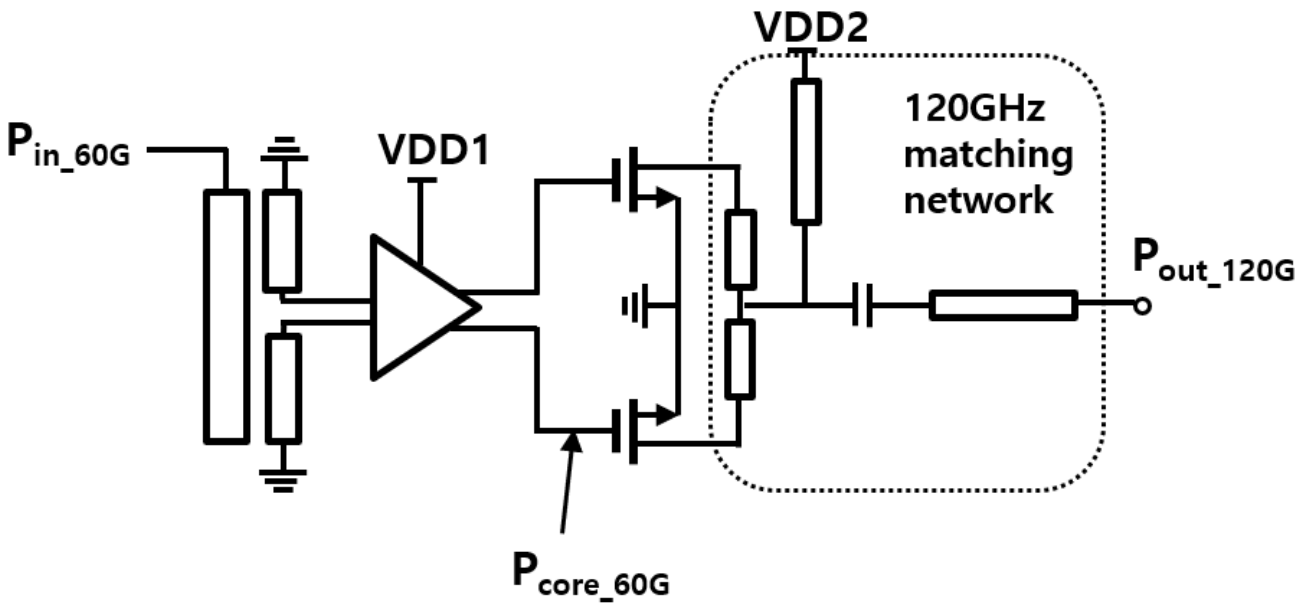


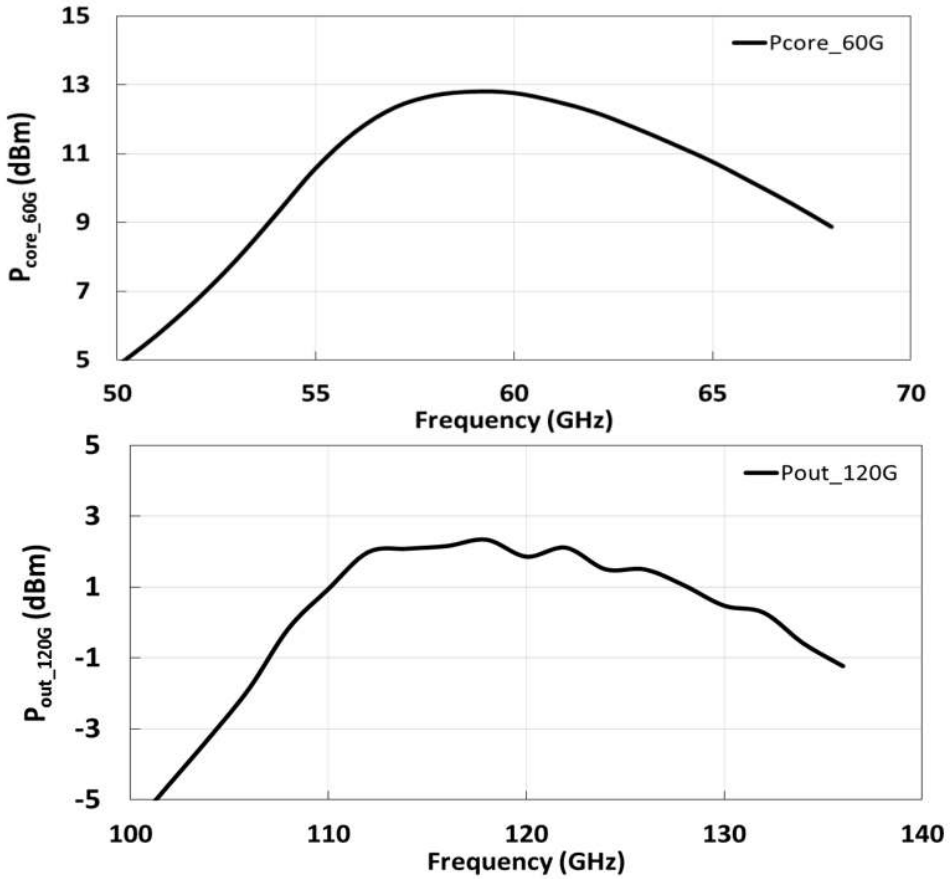




120 GHz Doubler

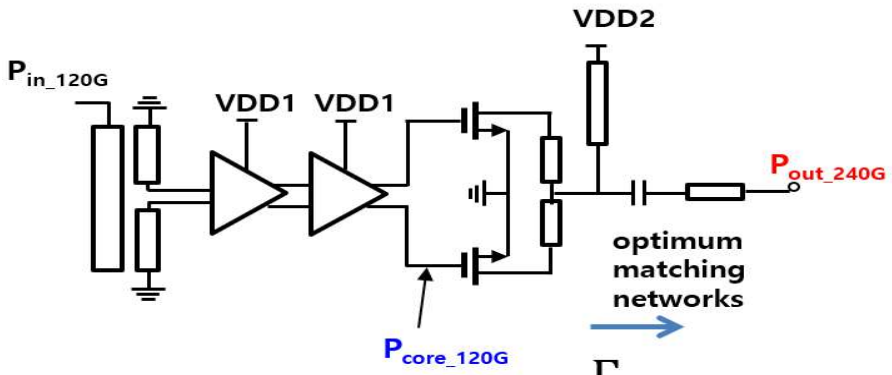
- Active balanced topology
  - 60 GHz Marchand balun, 60 GHz drive amplifier, Balanced doubler core



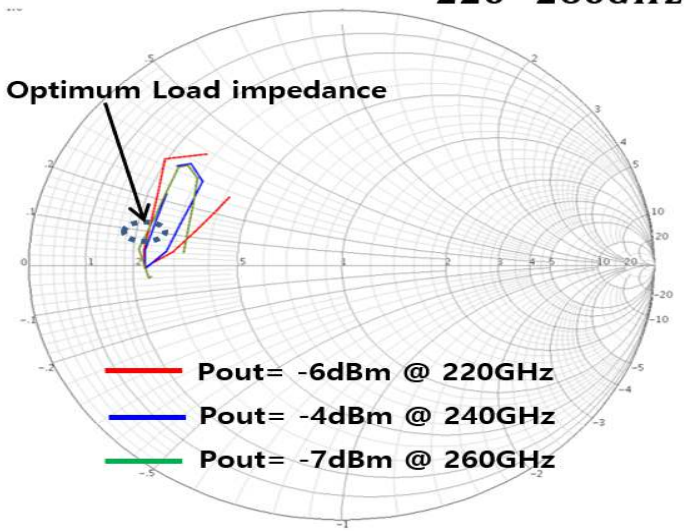


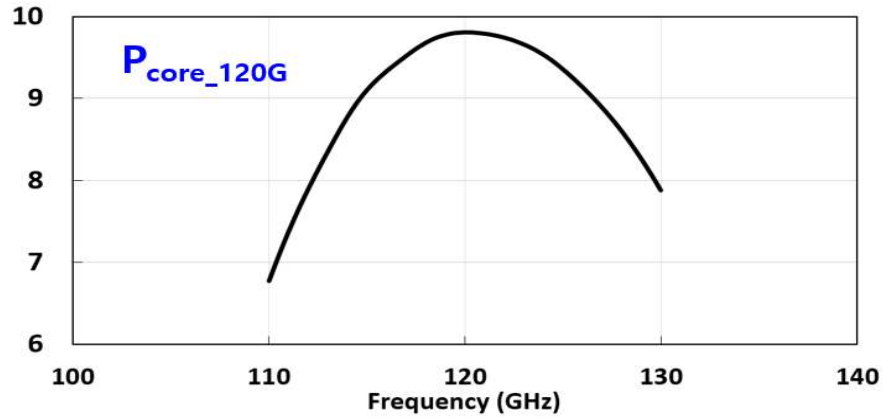
240 GHz Doubler

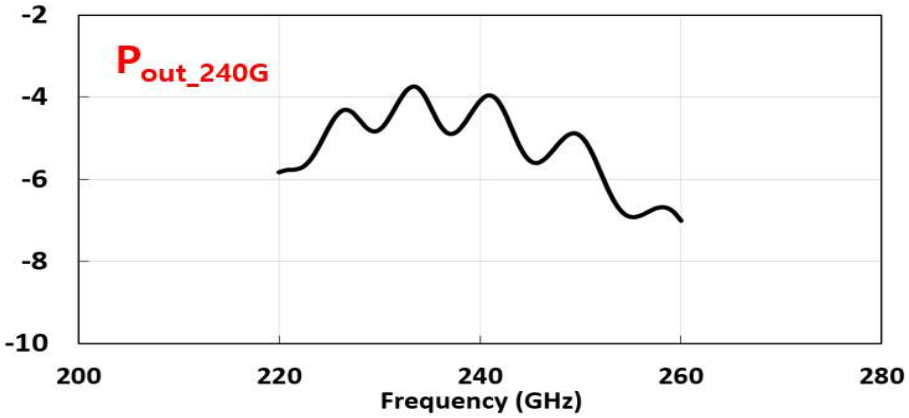
- Active balanced topology
  - 120 GHz Marchand balun, 120GHz drive amplifier, Balanced doubler core



$\Gamma_{220\sim260GHz}$

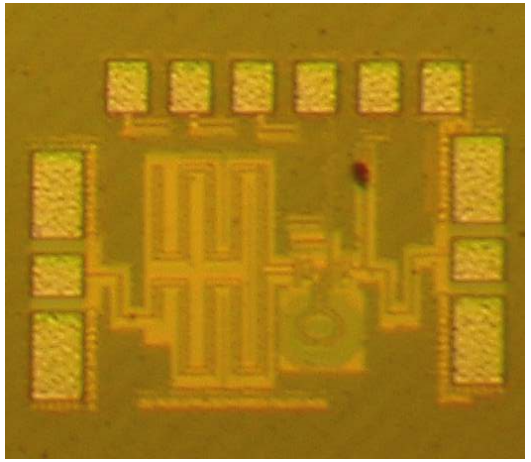


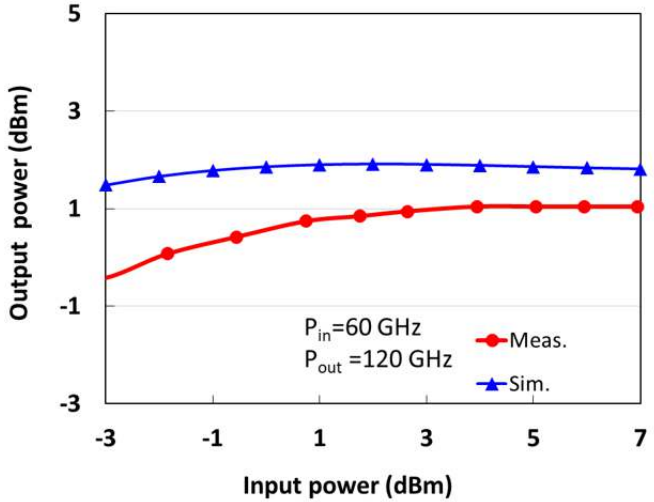


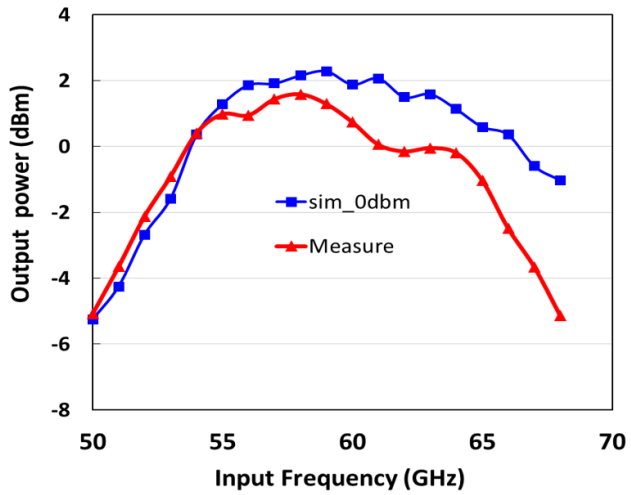


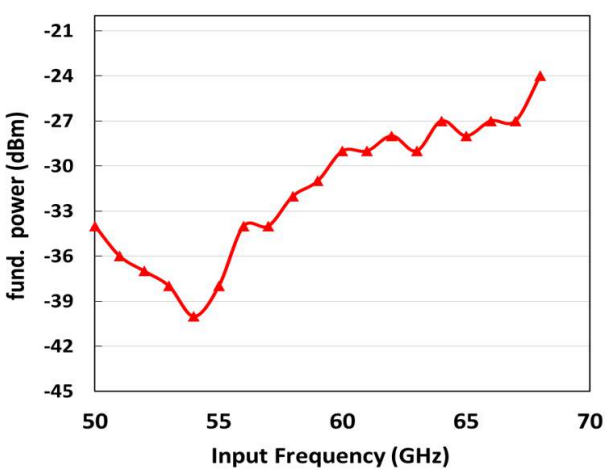
120 /240 GHz Doubler TP

- 120 GHz doubler Test Pattern

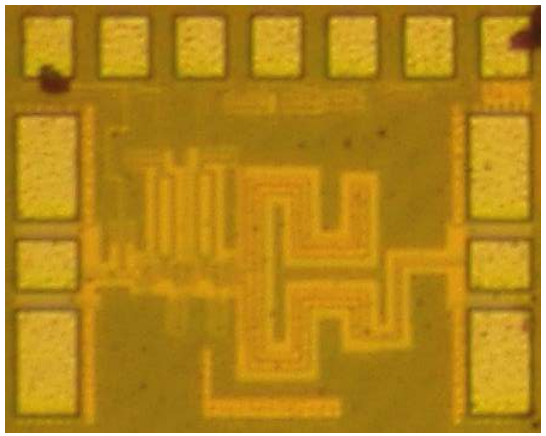


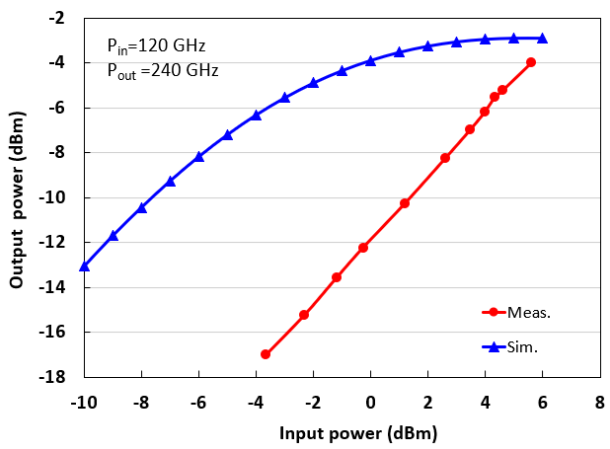


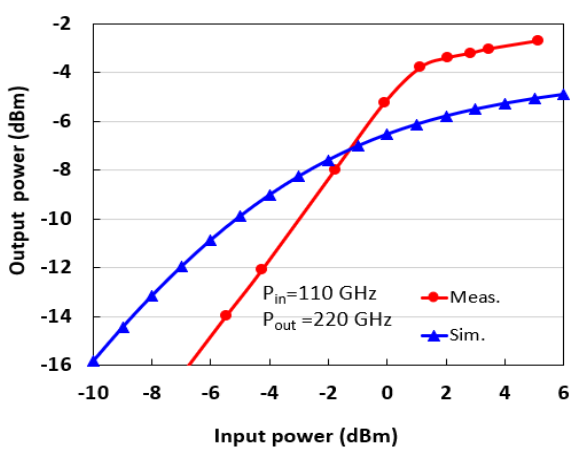


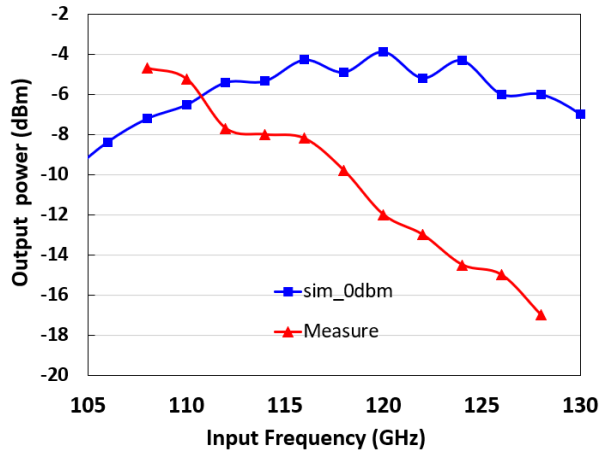


- 240 GHz doubler Test Pattern



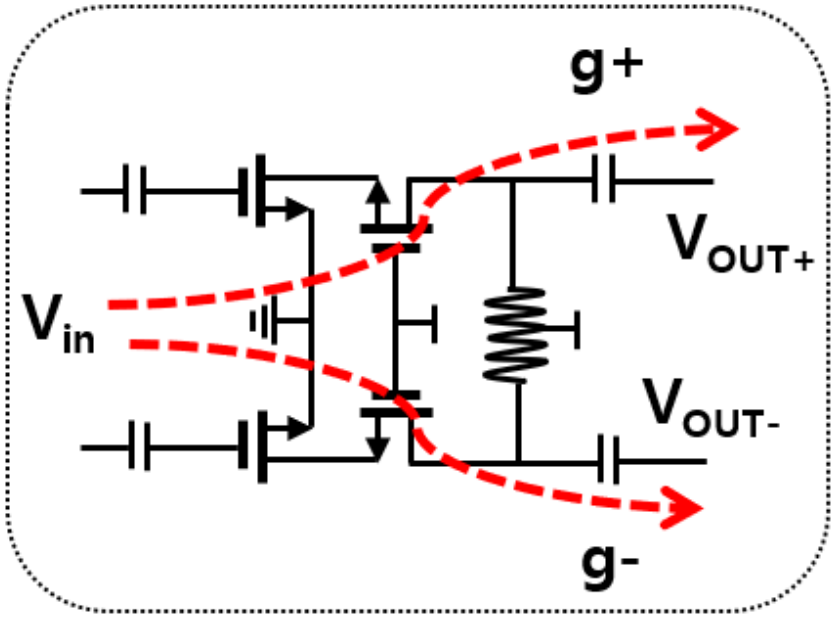


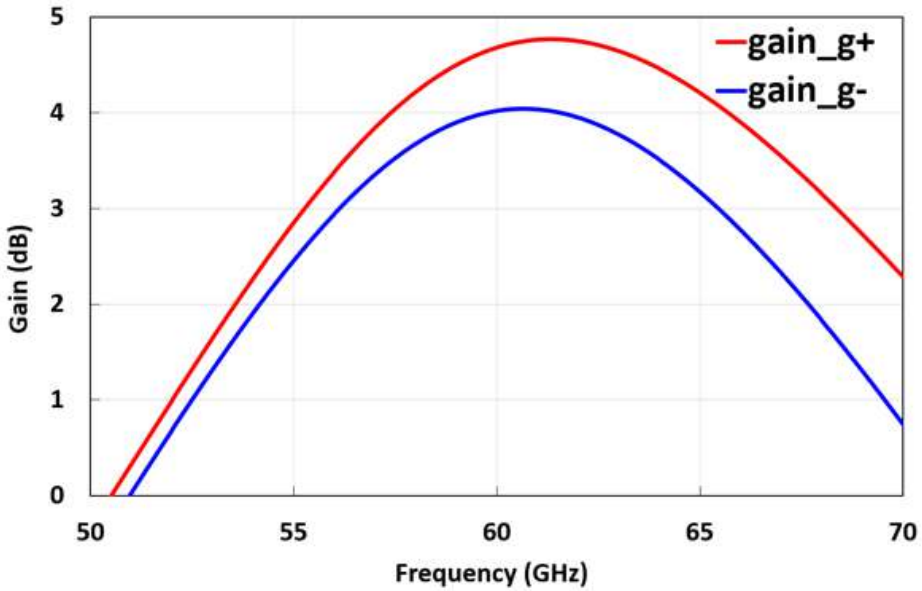




Active Divider

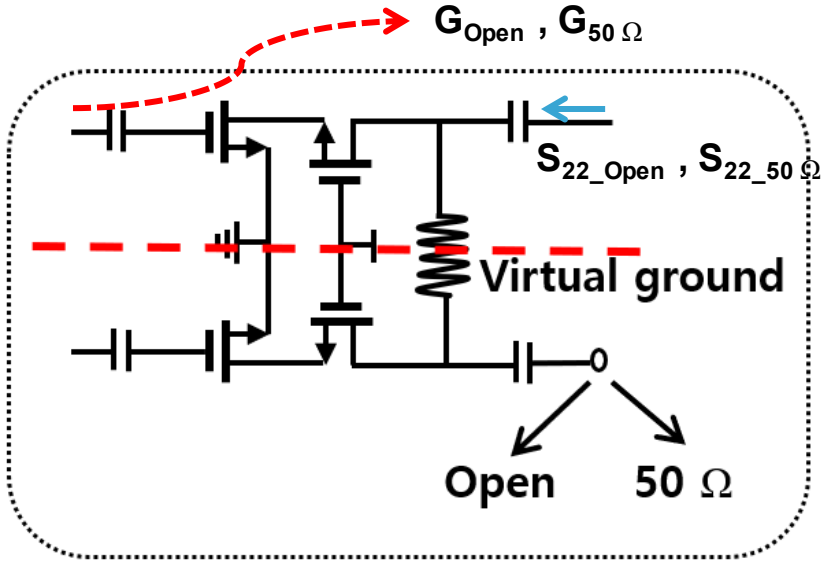
- 60GHz differential amplifier
  - Gain > 3 dB & Gain difference < 1 dB
  - Working as only amplitude divider

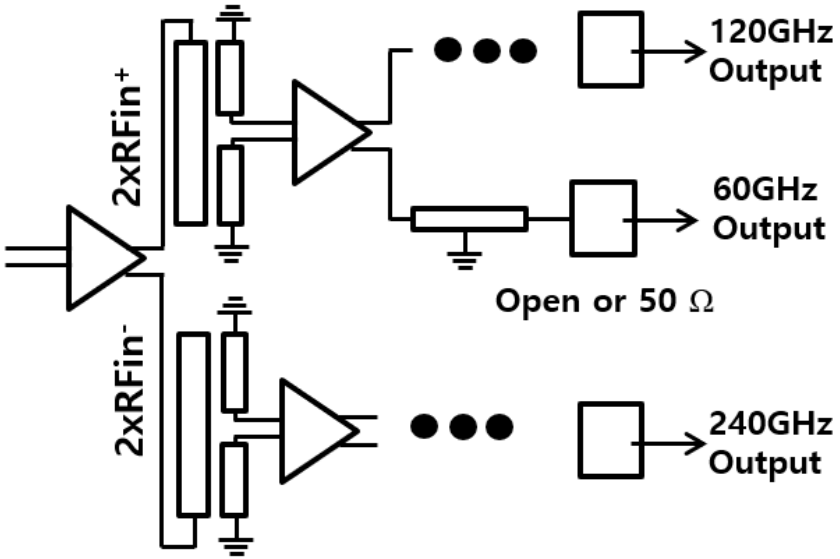


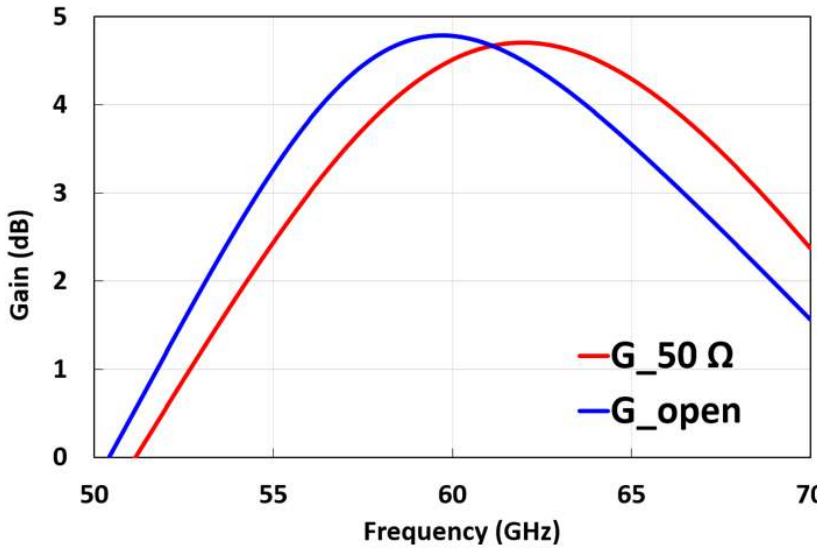


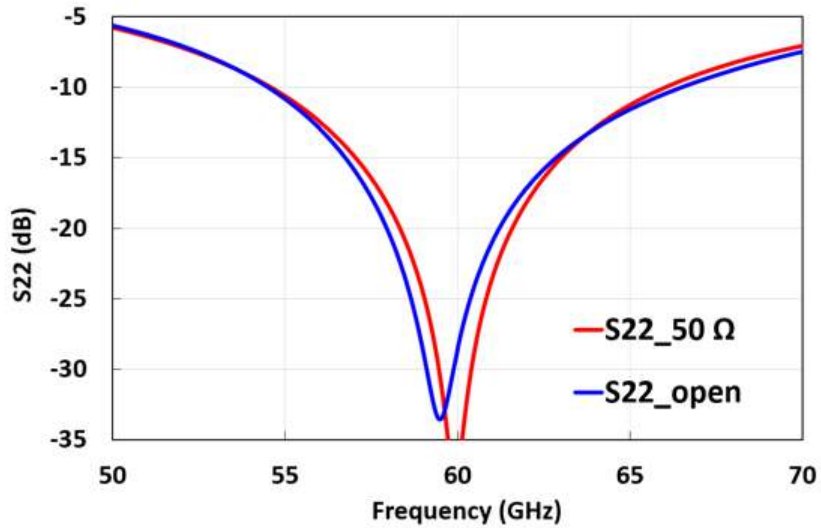
Active Divider

- 60GHz differential amplifier
  - 60GHz Output conditions (Open or 50 Ω)
  - Gain & Output Matching are slightly changed



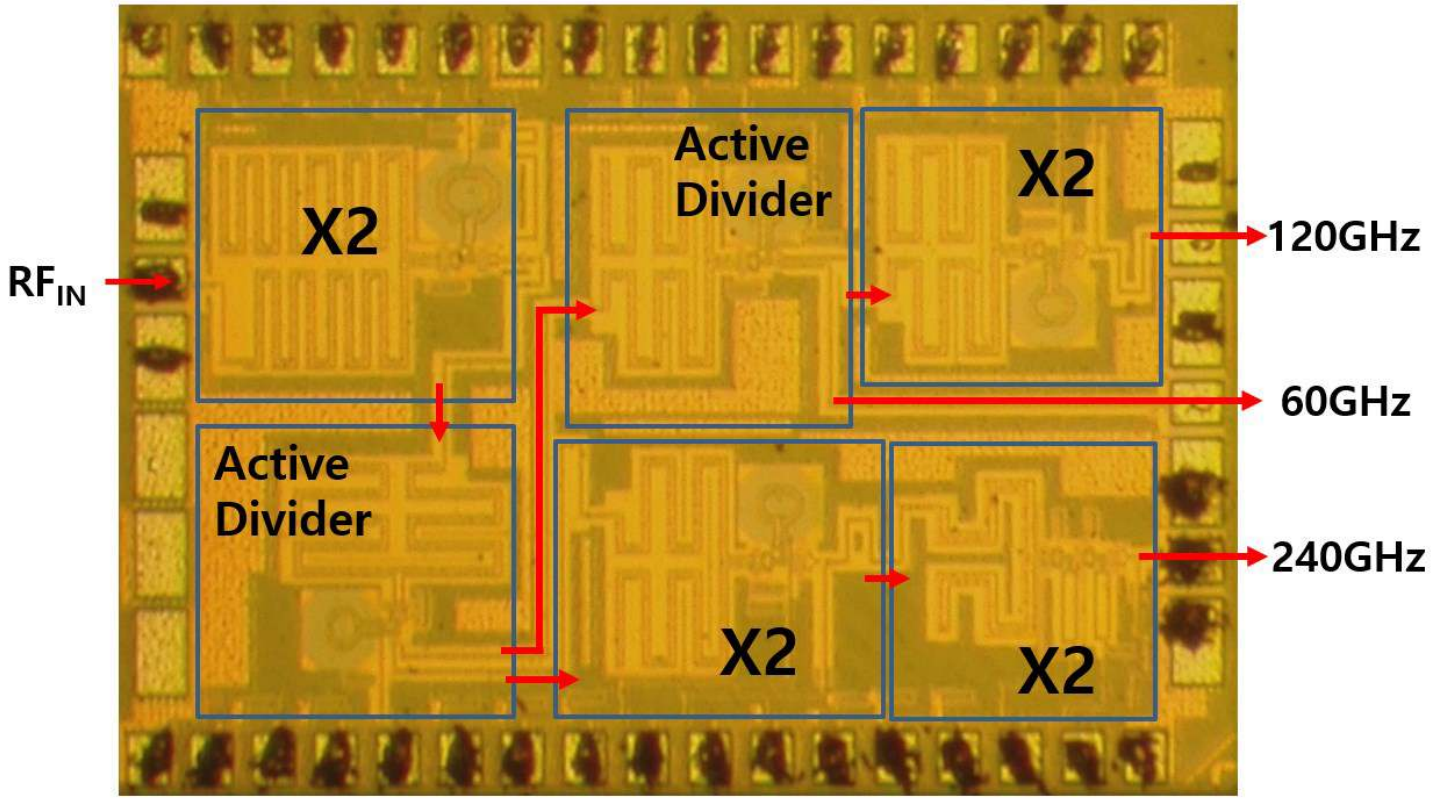






Implementation

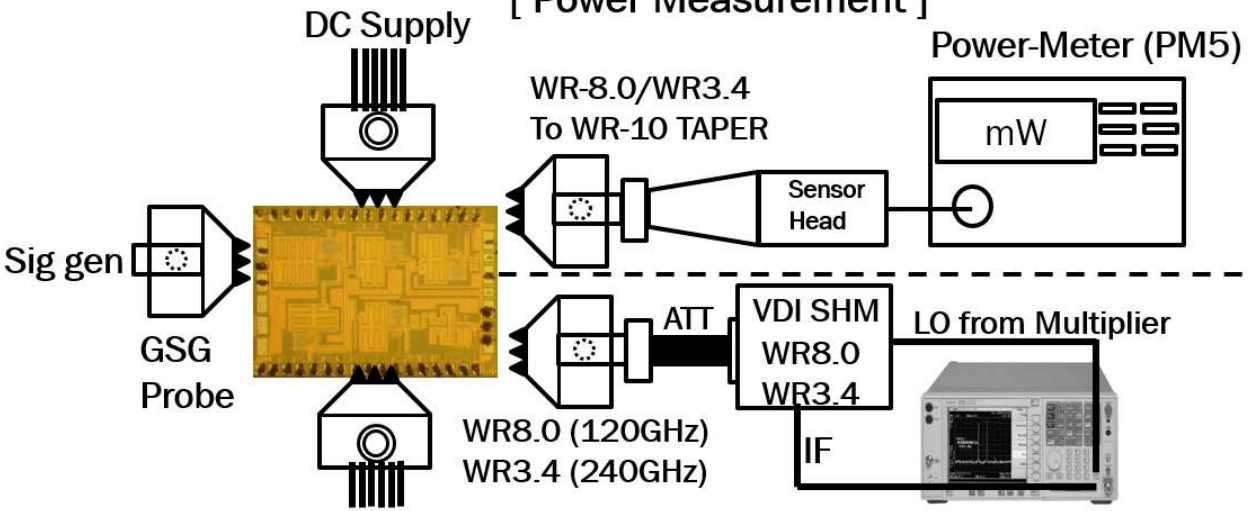
- Size: 1.3 mm x 0.9 mm (40nm CMOS Technology)
- Power Consumption: 1.1 V / 70 mA, 1.8 V / 110 mA



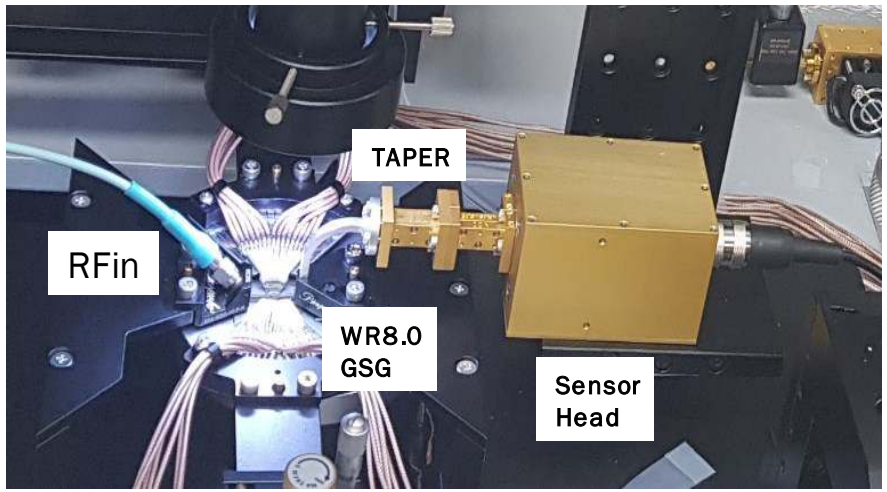
Measurement Setup

[60GHz Band Measurement]

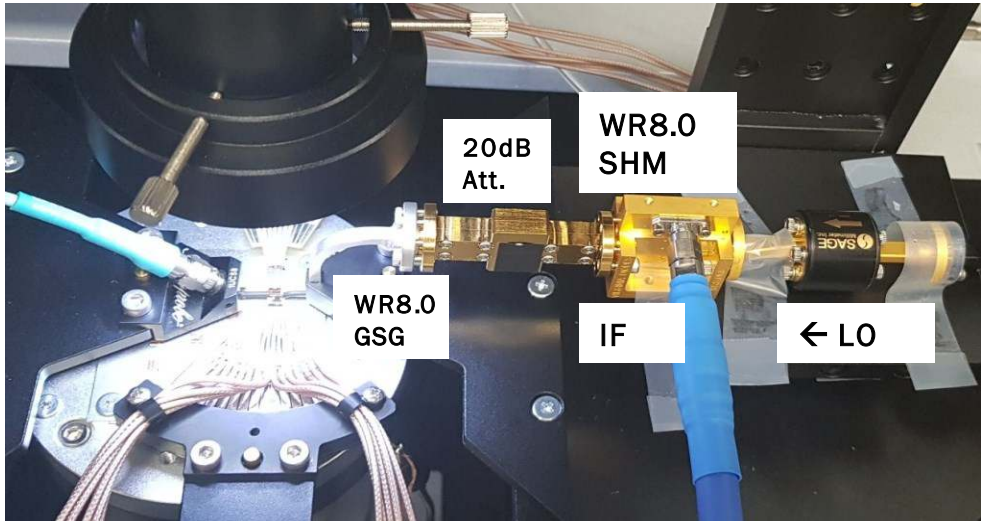
[Power Measurement]



[Spectrum Measurement]



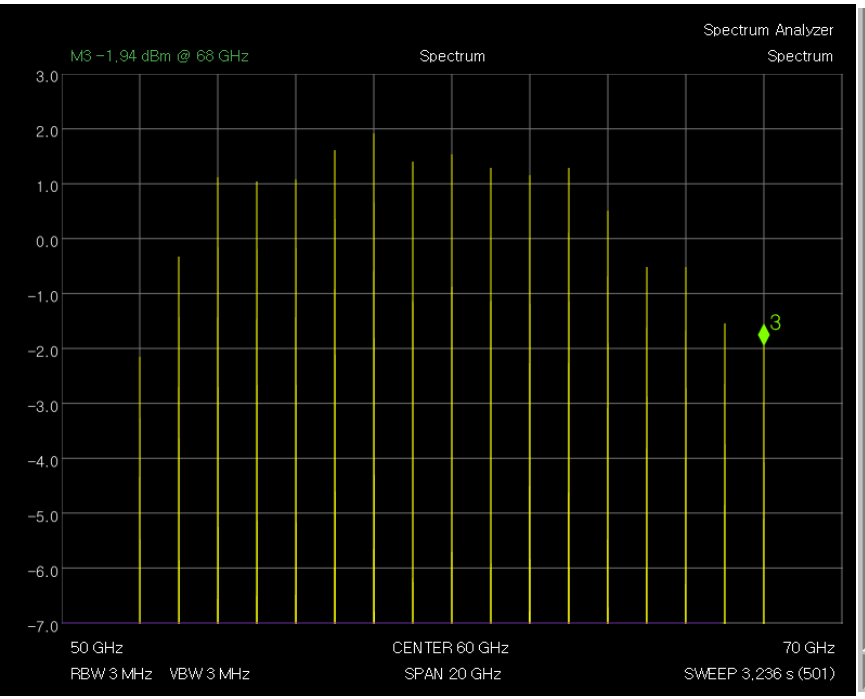
[120GHz Band Power Measurement]

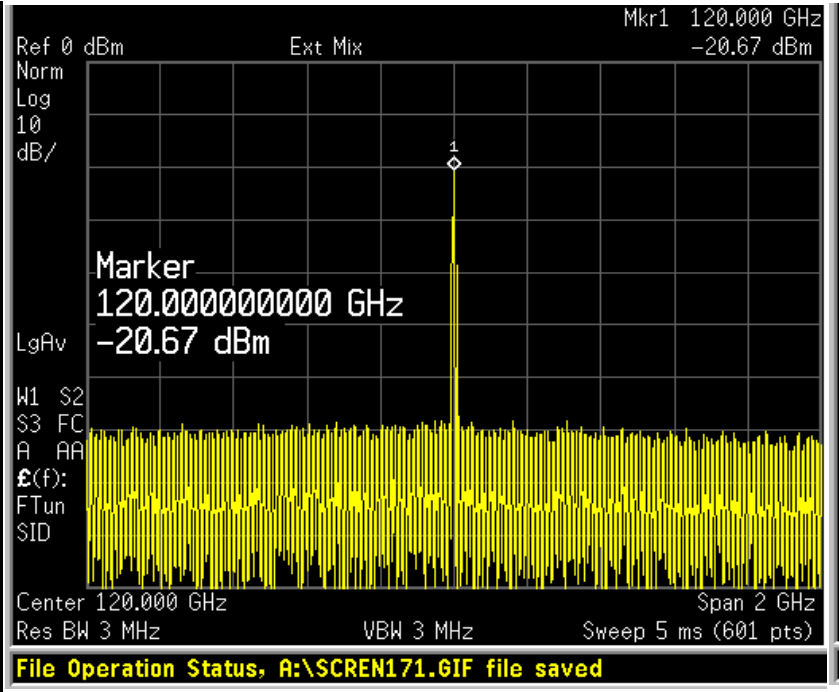


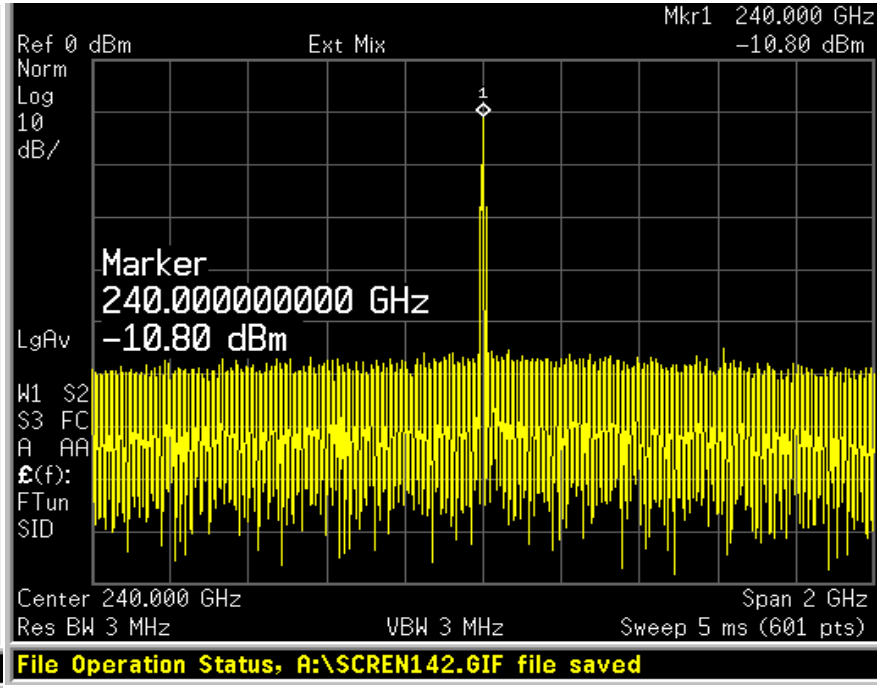
[120GHz Band Spectrum Measurement]

Measured Results

- Spectrum Results

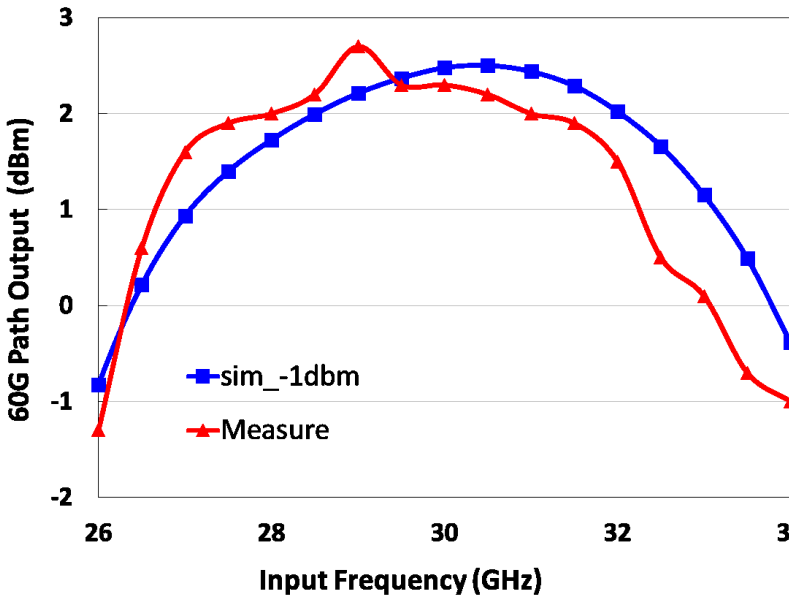


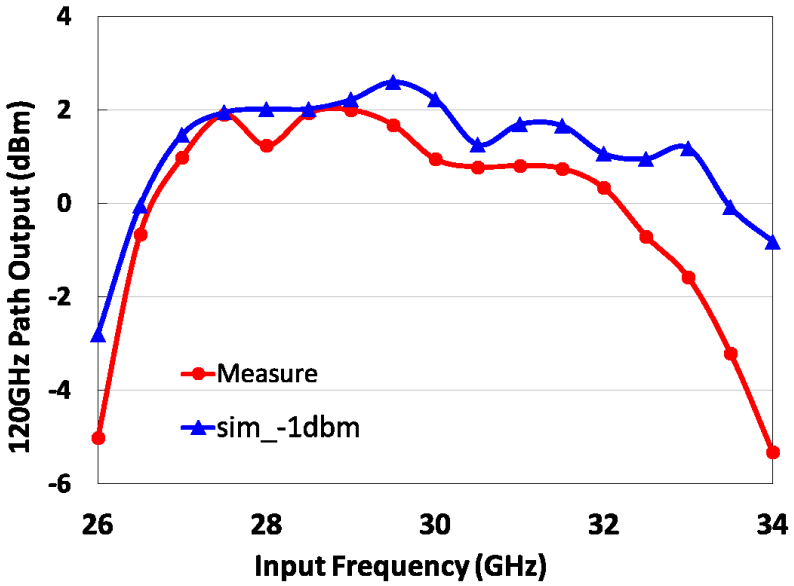


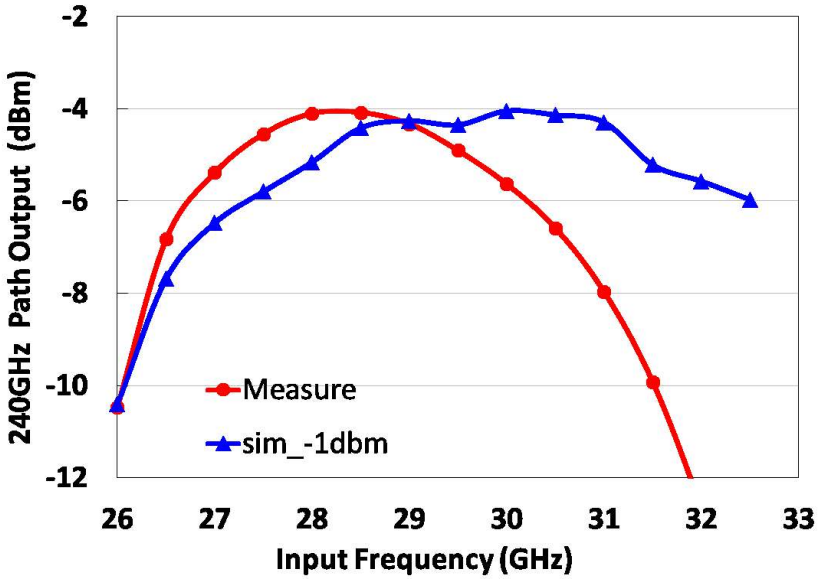


Measured Results

- Power Meter Results

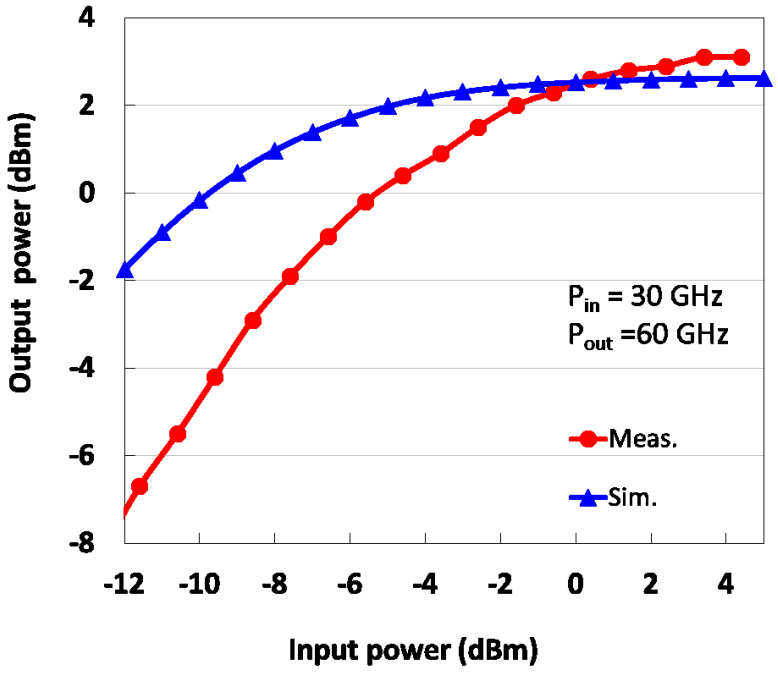


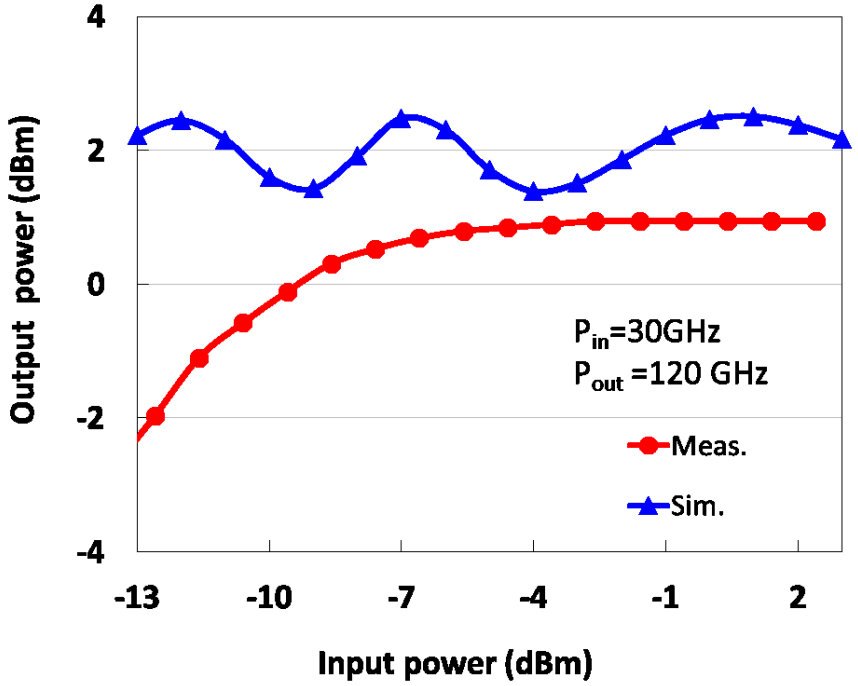


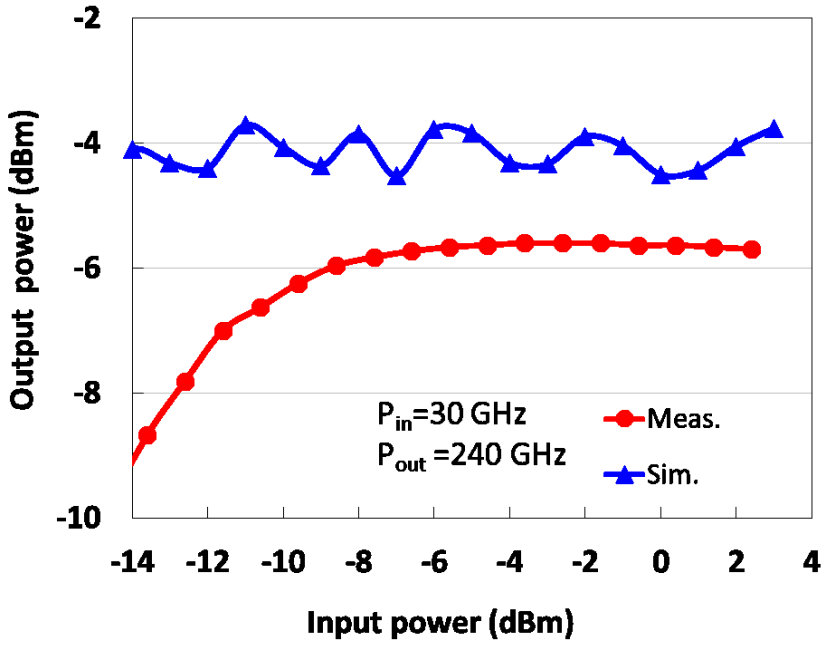


Measured Results

- Power Meter Results







Summary

- mmW to Sub-Terahertz source generation in single CMOS chip
- Three separate frequencies from 54 GHz to 252 GHz
- Each output covers a fractional bandwidth of 14 ~ 20%
- Can extend to WR-15 (50~75GHz), WR-08 (90 ~ 140 GHz), and WR-04 (170~ 260 GHz) using wideband driving amplifier