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The Design of a Plastic Packaged Front-end IC for mmWave 5G

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Presentation Overview

- Semiconductor technologies for mm-wave ICs
- Packaging options for mm-wave
- Design examples: Mm-wave front-end covering the FCC licensed 28GHz 5G band at 27.5 to 28.35GHz:
  - IC architecture and realisation
  - Packaging and evaluation PCB
  - Measured performance of transmit path
  - Measured performance of receive path
- Summary/conclusions

Process Options for MM-Wave ICs

Relative cost and RF Power

Function	Single die saturated RF output power	Cost per unit area
CMOS	10 to 20mW	$
SiGe	50 to 100mW	$$
GaAs PHEMT	2 to 3W	$$$
GaN	10 to 15W	$$$$

- Note:
  - Power levels are the approximate practical levels for a single commercial PA die, not the absolute maximum achievable power in the technology
  - The cost column is comparative, it is not intended to indicate a multiplying factor

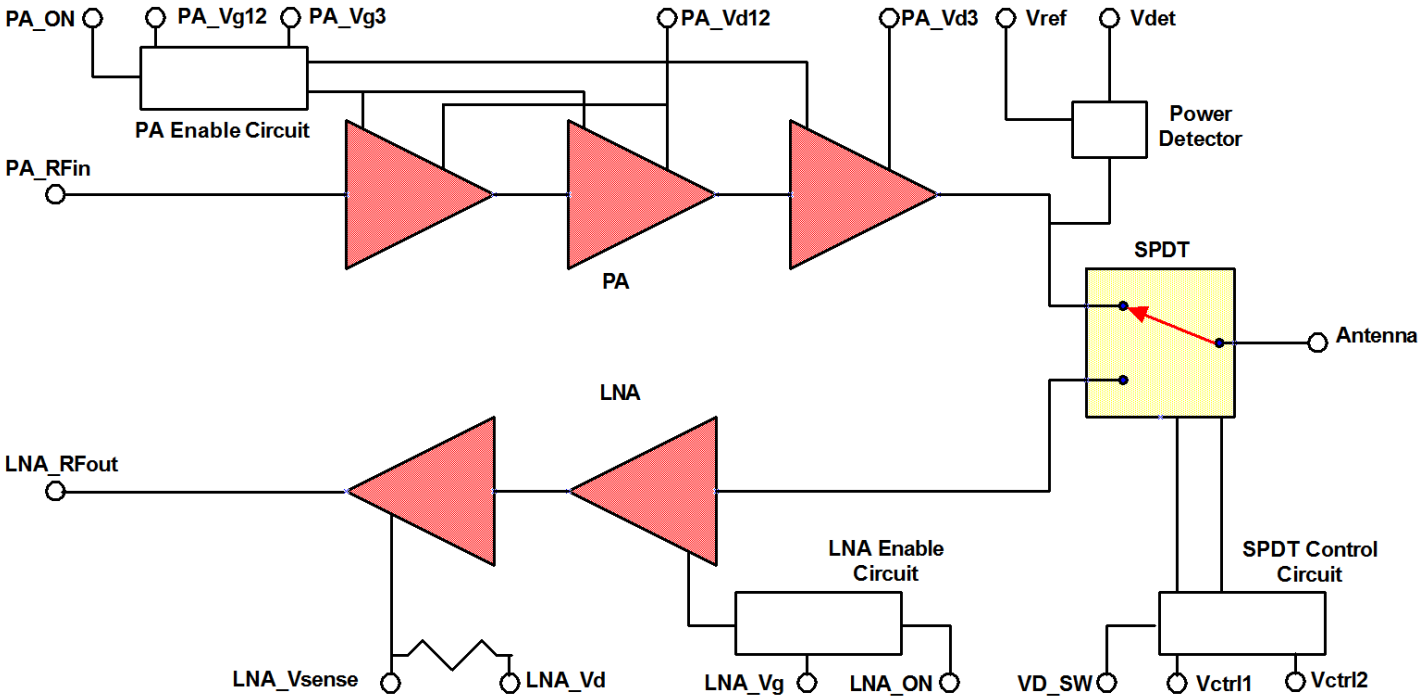
Packaging Options and Trends

For microwave and mm-wave ICs

The frequencies in the table below are guidelines rather than hard limits:

Style	Typical Frequency	Comments
Over-moulded plastic	To ~ 35GHz	Often uses custom leadframe
Air-cavity plastic	To ~ 42GHz	Normally uses custom leadframe
Laminate	To ~ 45GHz	Normally custom designed for higher frequency use
Wafer Level CSP	To ~ 80GHz	Die is flip-chipped
Multi-Chip Modules	To 100GHz	Bare die assembled into custom substrate
Integral Antennas	> 100GHz	Multi-elements commonly used

Block Diagram of the FEM IC



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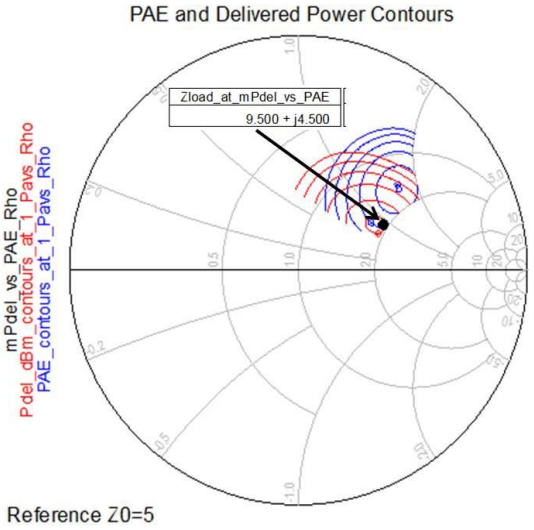
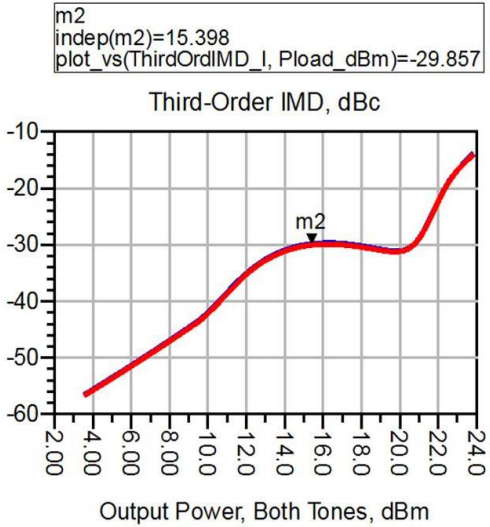
Key Performance Targets

- Operating frequency: 27 to 29GHz
- DC bias +4V (no negative supply)
- Tx Performance (*SMT packaged part on PCB*):
  - P-1dB > 20dBm (PAE > 20%) – *includes switch and package losses*
  - PAE at 35dBc IMD3 (~7dB back-off) > 6%
  - Gain ~ 17dB with IP3 > 27dBm
- Rx Performance (*SMT packaged part on PCB*):
  - NF < 3.5dB – *includes switch and package losses*
  - Gain > 13dB; Idd < 15mA
  - IP3 > 15dBm

Preliminary Simulations to Select Device Size, Bias and Load Impedance (#1)



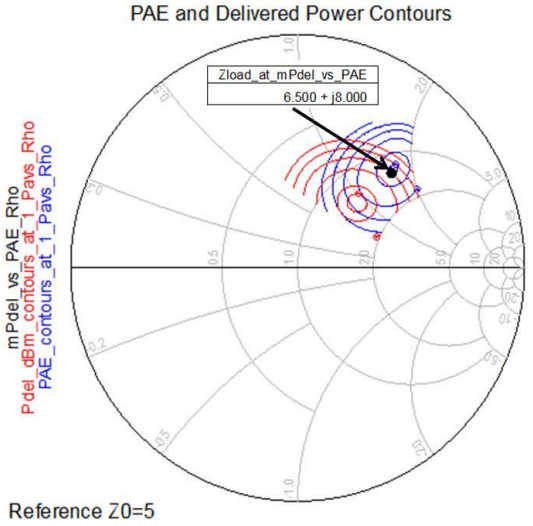


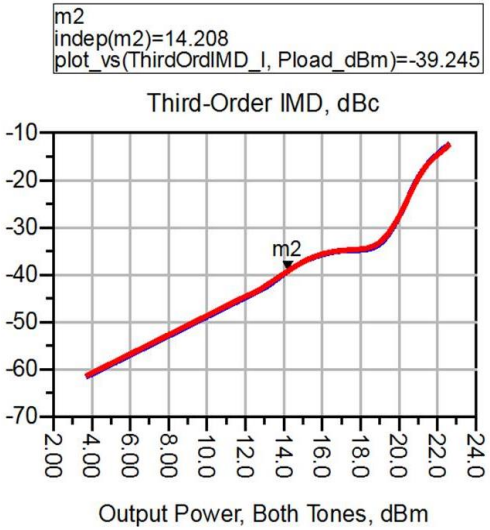
Load for optimum **Power** at 1dB Compression for 8x50µm device biased at 75mA/mm at 4V

Corresponding IMD3 at around 7dB Back-off = 29.8dBc and PAE = 15.7%

Power match – *highest P-1dB but can't meet IMD3 spec of 35dBc at ~7dB Back-off*

Preliminary Simulations to Select Device Size, Bias and Load Impedance (#2)



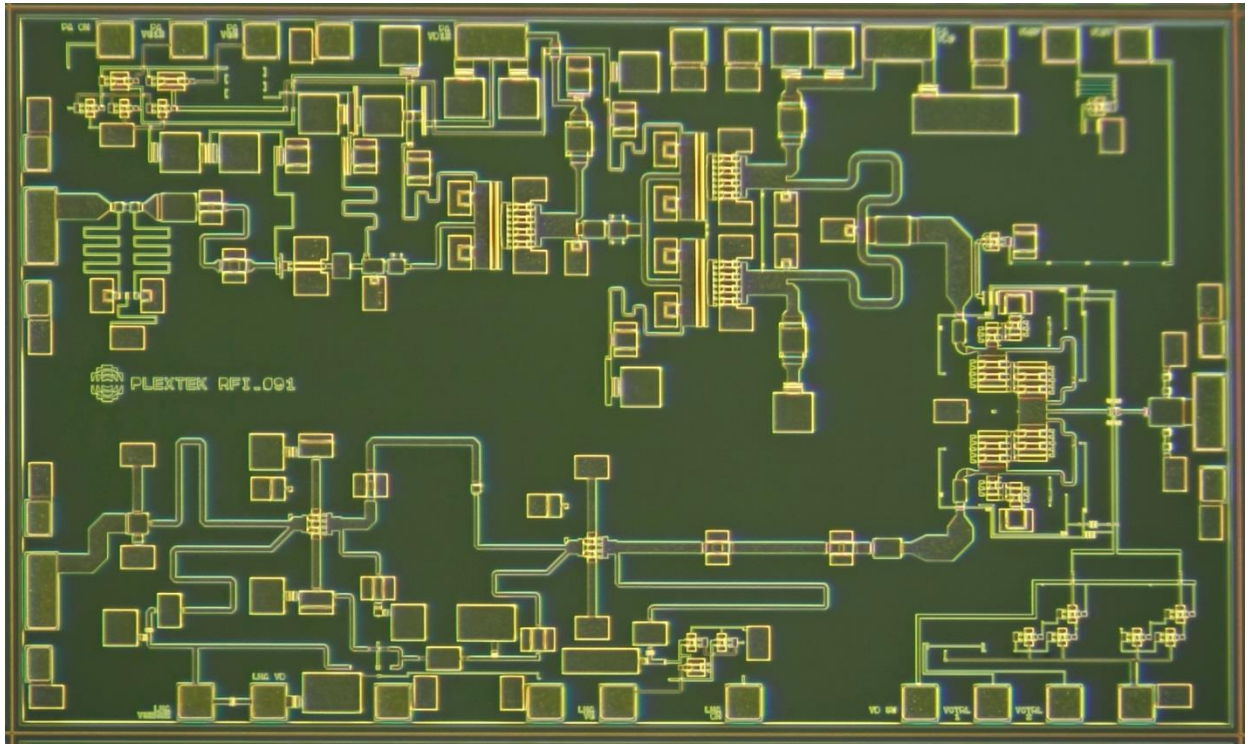


Load for optimum **PAE** at 1dB Compression for 8x50µm device biased at 75mA/mm at 4V

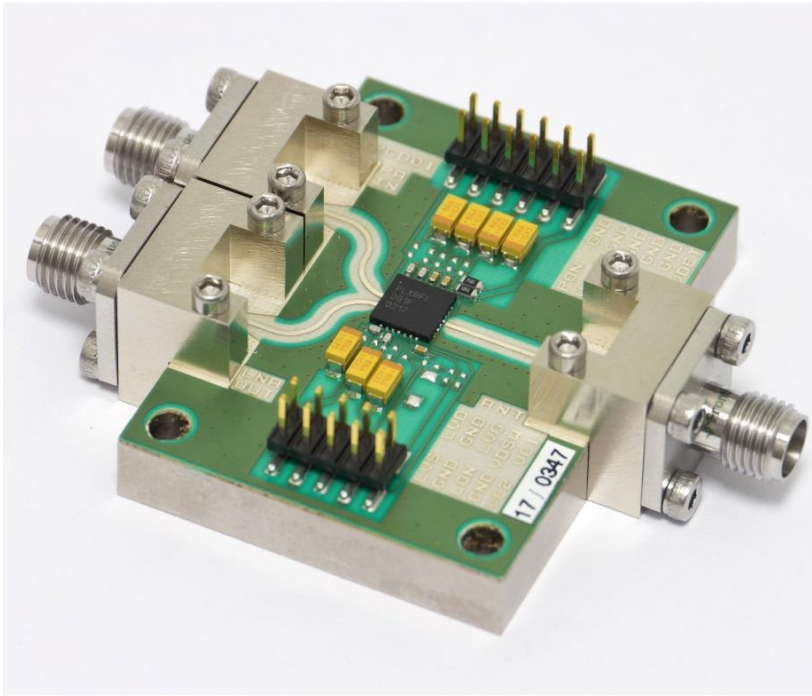
Corresponding IMD3 at around 7dB Back-off = 39.2dBc and PAE = 15.0%

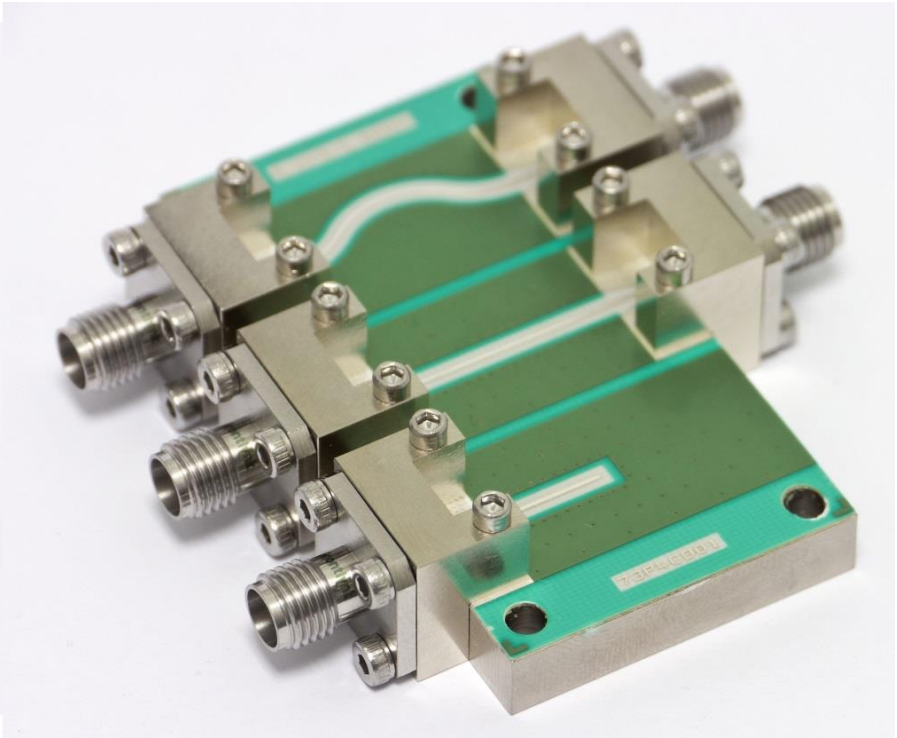
PAE match (selected) – *similar back-off PAE as power match but much better IMD3*

Photograph of the FEM Die



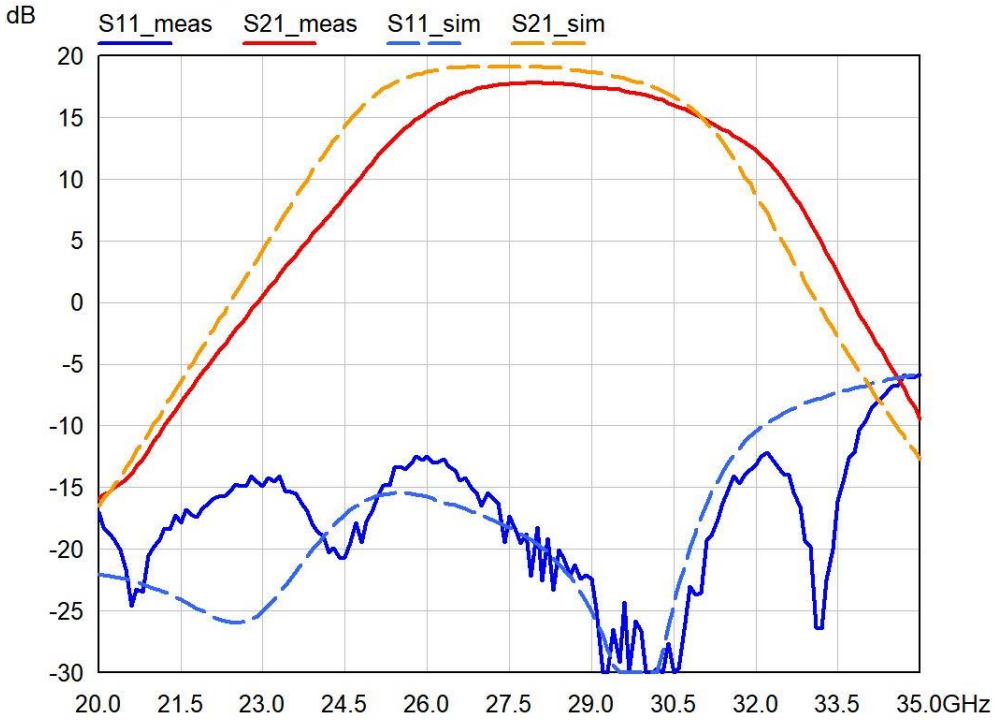
FEM Evaluation PCB and TRL Calibration Tile





Measured and Simulated S-parameters of Tx Path

(Vdd =4V; Idq = 70mA)



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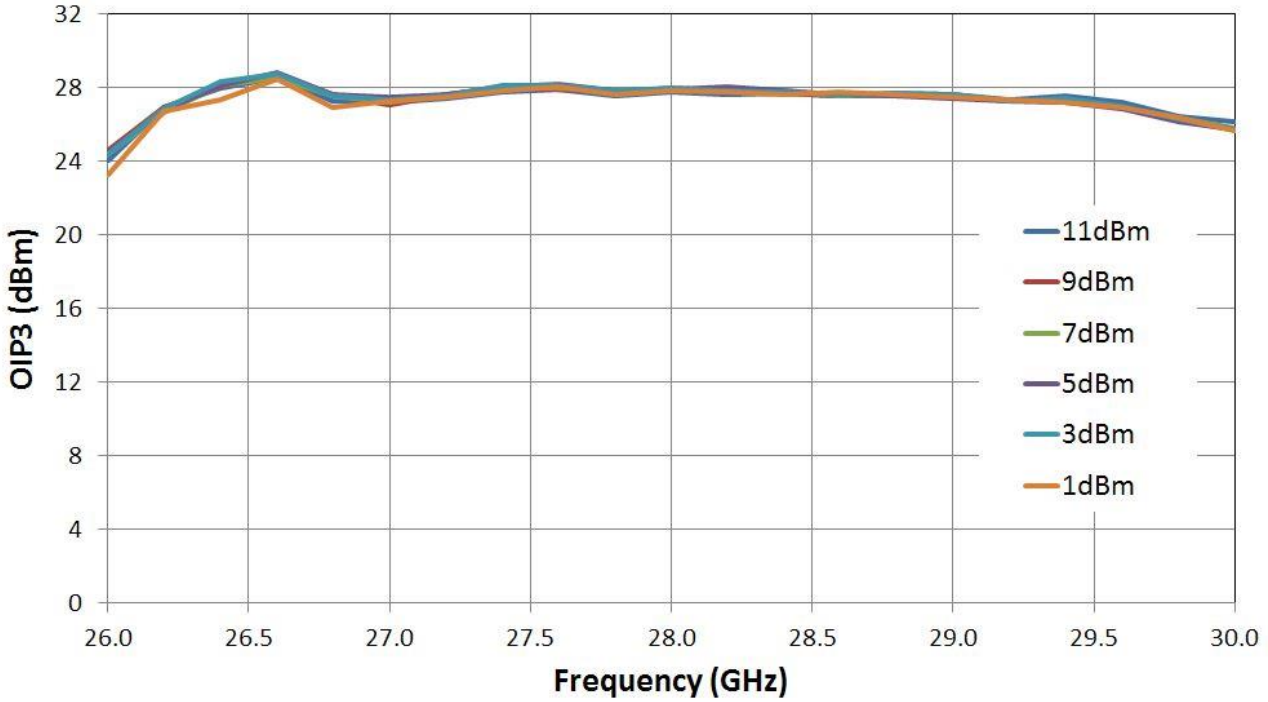
Measured OIP3 of the Tx Path versus Frequency for Different Signal Levels



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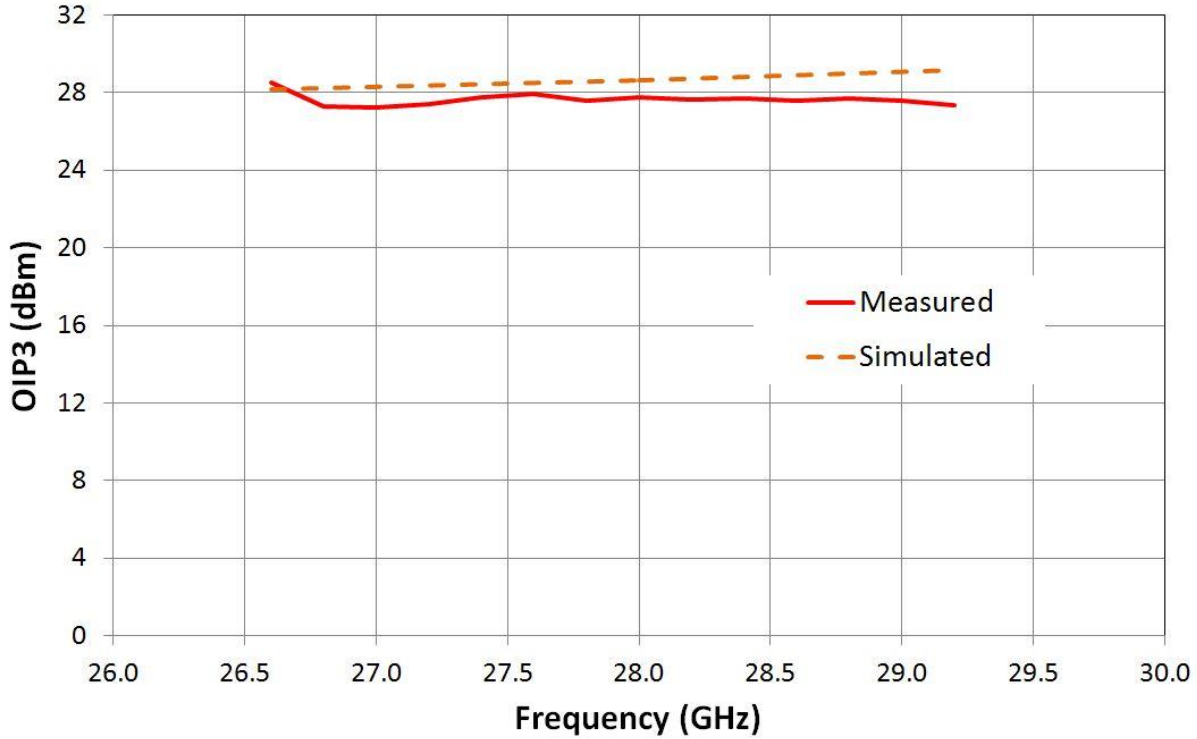
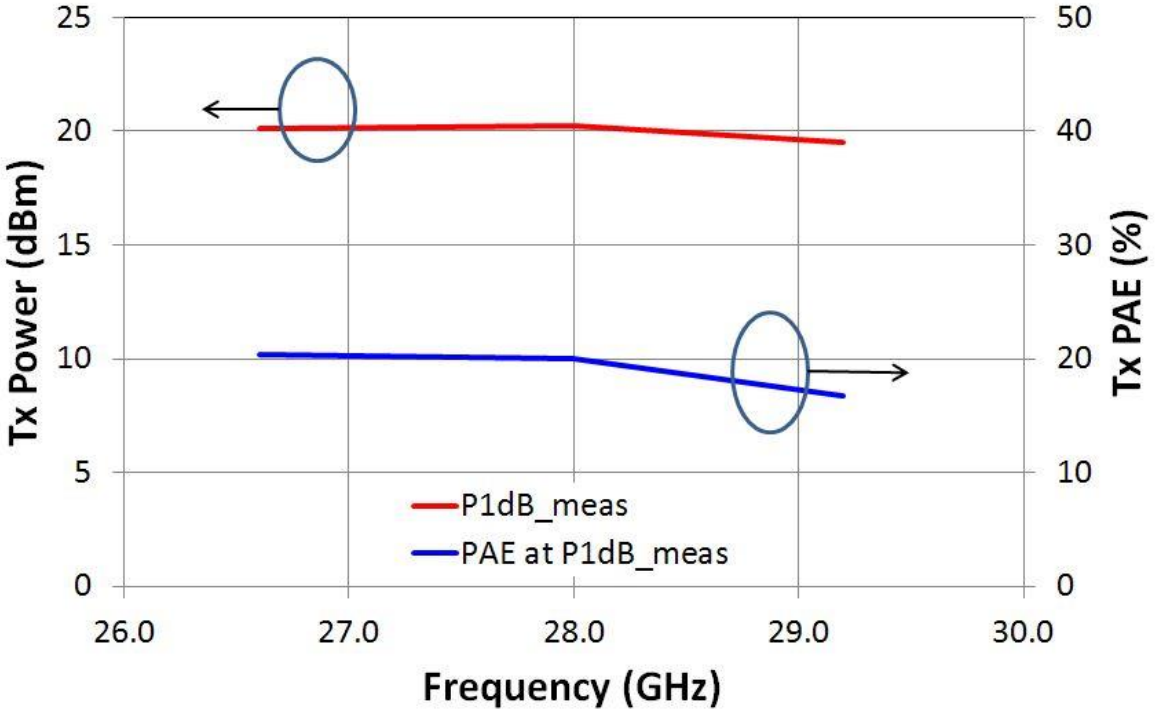
Comparison of Measured to Simulated OIP3 versus Frequency



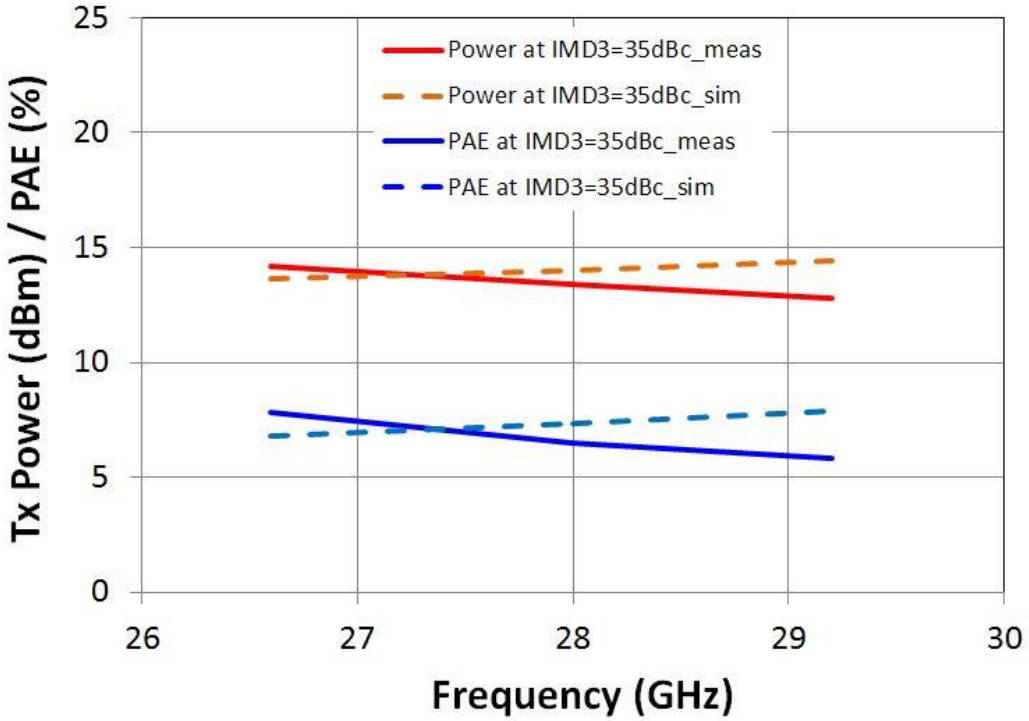
Measured Tx Path P-1dB and PAE versus Frequency

(Vdd =4V; Idq = 70mA)



Measured to Simulated Tx Power and PAE

Operating at ~ 7dB Backed-off



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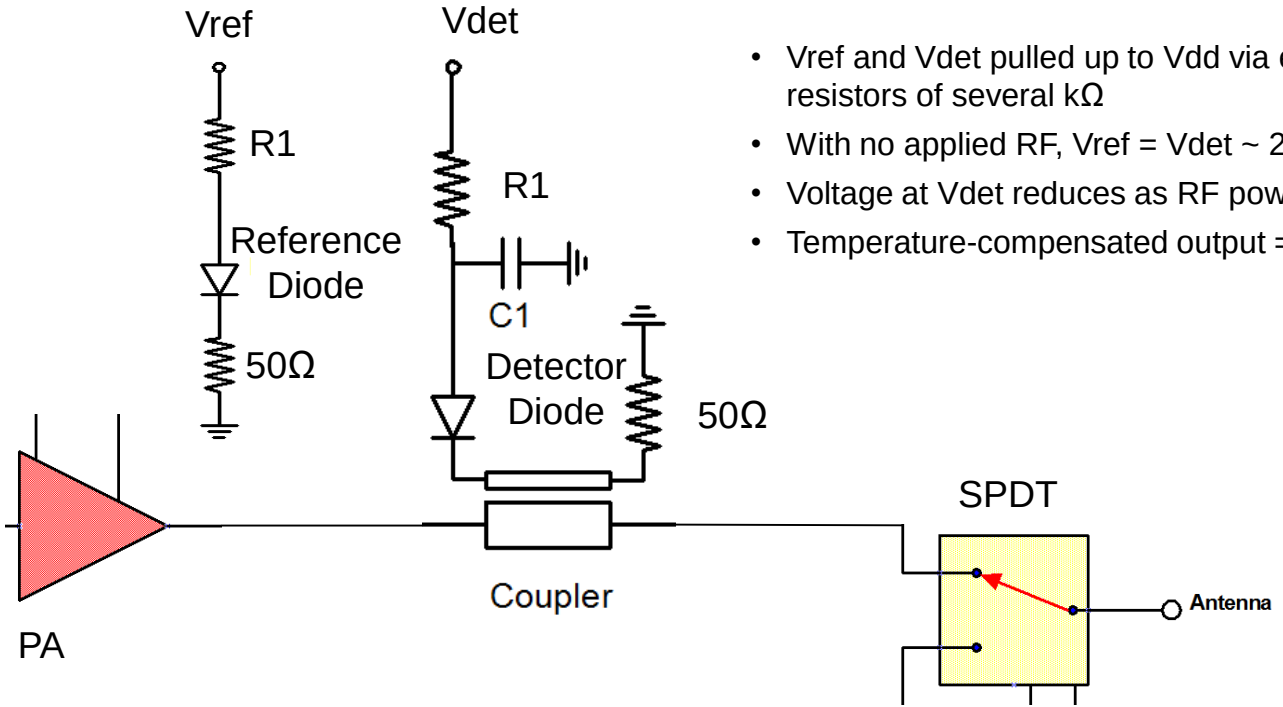
FEM Tx On-Chip Power Detector Schematic



- Vref and Vdet pulled up to Vdd via external resistors of several kΩ
- With no applied RF, Vref = Vdet ~ 2V
- Voltage at Vdet reduces as RF power increases
- Temperature-compensated output = Vref-Vdet

FEM Tx On-Chip Power Detector Measured Characteristics at 28GHz

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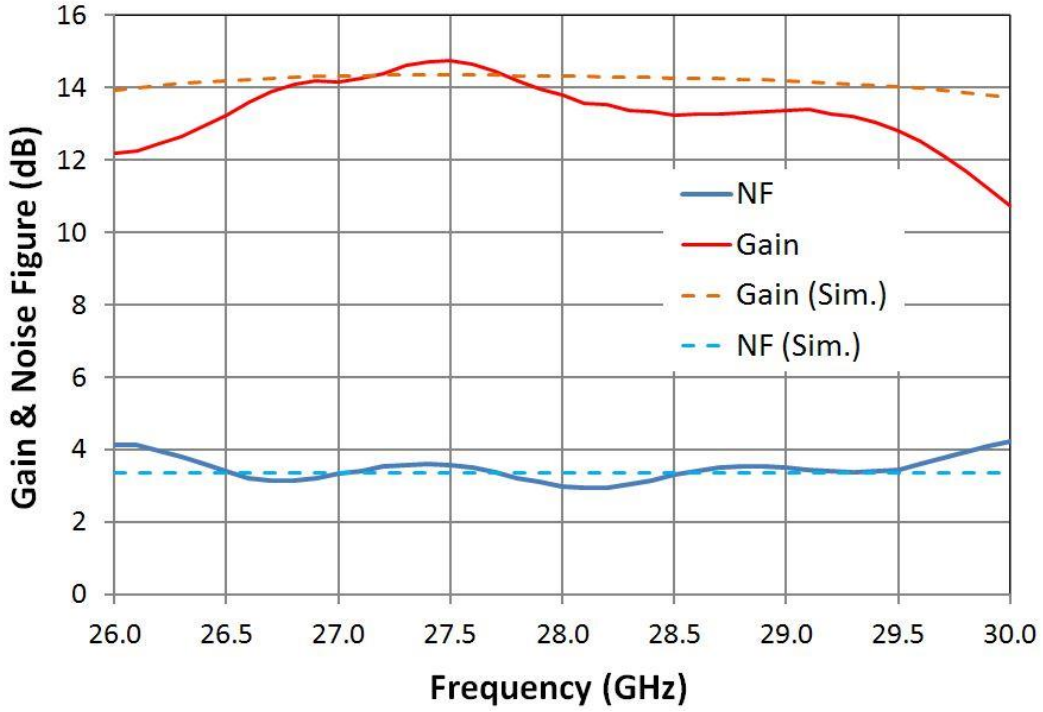
Comparison of Measured to Simulated Gain and NF for the Rx Path - DC Bias is +4V and 10mA



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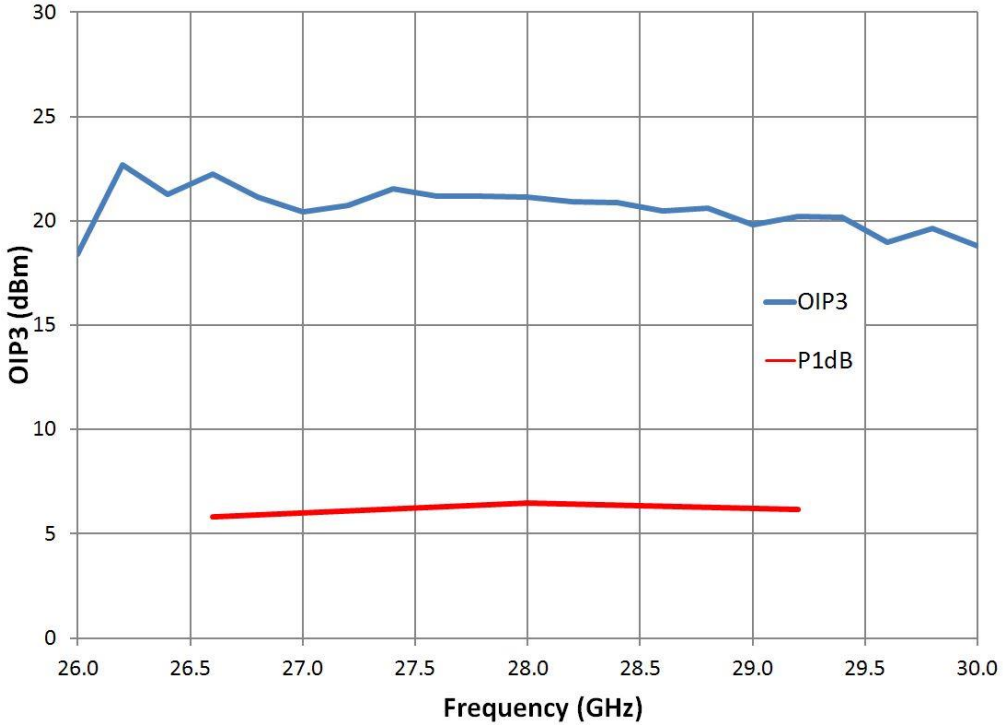
Measured OIP3 and P-1dB versus Frequency for the Rx Path - DC Bias is +4V and 10mA



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Summary/Conclusions

- A single chip FEM has been developed comprising LNA, PA, RF power detector, Tx/Rx switch and control circuitry
- Covers the FCC licensed 28GHz 5G band at 27.5 to 28.35GHz
- The IC is housed in an 5mm x 5mm over-moulded QFN package
- Performance of parts soldered to a representative evaluation PCB has been presented:
  - Tx path P-1dB of > 20dBm with PAE of ~ 20%
  - Tx path PAE at around 7dB back-off of around 7%
  - Rx path gain of 13.5dB with a NF of ~ 3.3dB from DC supply of 10mA at 4V
  - Rx path IP3 ~ 20dBm