Case Studies on the "Millimetre-wave and Terahertz On-chip Circuit Test Cluster for 6G Communications and Beyond (TiC6G)" programme

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The demand for high data transmission rates in wireless and mobile communications, high resolution in radar and remote sensing as well as next generation quantum computing drives the carrier frequency to the higher millimetre-wave range, e.g., beyond 100 GHz. The next generation of mobile networks, 6G, is expected to generate greater diffusion and provide technical platforms to address social, economic, and humanitarian issues with higher data rates (x50 compared to 5G), wider bandwidth (20 GHz), and lower latency (sub-milliseconds). The urgency and challenges require the development of revolutionary technologies to meet the projected performance levels. Several universities and organisations have been investigating enabling technologies, including quantum cascaded lasers (QCL), resonant tunnelling diodes (RTD), high electron mobility transistors (HEMTs), and heterojunction bipolar transistors (HBT), etc. However, there is a distinct lack of enabling test capabilities for chip-level developments, which form the core of any communication system.

In this talk, we present measurement case studies to benchmark the recently completed TiC6G test cluster, which is an EPSRC-funded strategic equipment grant, titled "Millimetre-wave and Terahertz On-chip Circuit Test Cluster for 6G Communications and Beyond (TIC6G)" (EP/W006448/1). The Cluster consists of three key modules: waveform generation, signal analysis, and device characterisation for both on-wafer and waveguide setups. The three modules can operate individually or collectively and are built around a semi-automated probe station.

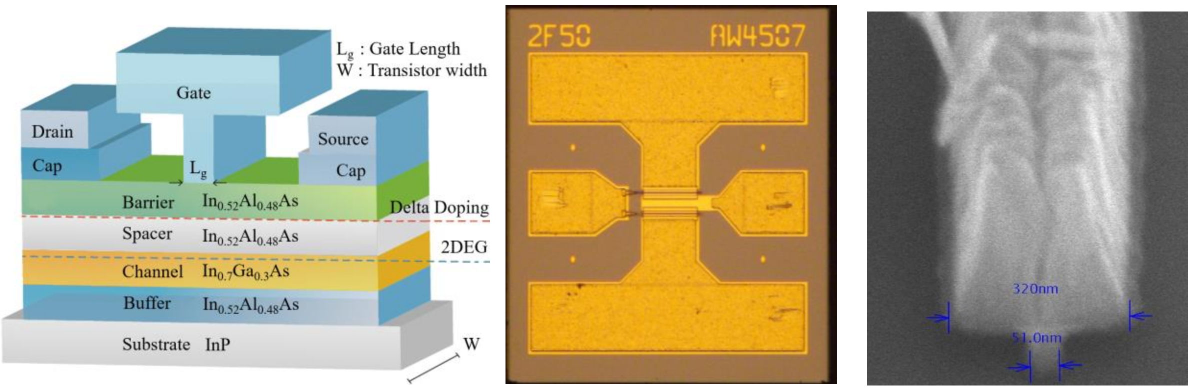
(a) (b)

Figure 1. Images of part of the TiC6G on-wafer test cluster for (a) noise parameter measurements between 2 GHz and 50 GHz (b) active load pull test system operating between 110 GHz and 170 GHz.

The waveform generation module can produce wideband (> 40 GHz) high-speed complex waveforms at beyond 110 GHz to meet the requirements of future communications. The signal analysis module can perform spectrum analysis of signal sources as well as real-time signal analysis on ultra-wideband, high data rate, complex signals in the time domain for frequencies beyond 110 GHz. Performing wideband modulated signal measurements directly on devices under test especially at their development stage i.e. on-chip in time-domain is necessary as such measurements can provide true performance of the devices. The device characterisation module permits noise parameter measurement (2 GHz – 50 GHz, Figure 1a), phase noise analysis (50 GHz), power measurements (up to 1.1 THz), S-parameter measurements (10 MHz – 1.1 THz), and active load-pull measurements (up to 1.1 THz, Figure 1b).

We have used high electron mobility transistors (HEMTs) which are both commercially available and fabricated at the University of Glasgow to benchmark the noise parameter setup for frequencies between

2 GHz and 50 GHz and the load pull system in the frequency range between 120 GHz and 170 GHz. Figure 2 illustrate the epitaxial layers of a typical HEMT, image of the commercial HEMT die, and the 50 nm “T”-shaped gate fabricated at the University of Glasgow. Previous numerical modelling on the commercial 100 nm HEMT showed that the device has a cutoff frequency of 215 GHz which is very close to the manufacturer claimed 220 GHz [1]; however, there is lack of experimental results on gain beyond 50 GHz at non-50 Ohm conditions. We tested the device using the active load system with a pair of GSG probe operating between 120 GHz and 170 GHz. Figure 3 shows the S-parameters of the device measured using a standard 50 Ohm vector network system when the gate-source voltage, Vg, and the source-drain voltage, Vd, were 0.1 V and 0.9 V, respectively. It can be seen that the device’s gain is between 2.5 dB and 1 dB in the frequency range of 120 GHz and 170 GHz. On the contrary, Figures 4 and 5 show the measured gain of the device using the load-pull system which are 6.8 dB and 4.6 dB at 140 GHz and 170 GHz, respectively. The results demonstrate that appropriate matching circuits are required to reflect the true performance of the device. More results on noise figure and noise parameter of this device and the improved noise and gain performance of Glasgow’s 100 nm HEMTs will be presented at the conference.



(a) (b) (c)

Figure 2. (a) Illustration of the epilayers of a typical pHEMT [1], (b) micrograph of the commercial HEMT die that has 2 fingers and a total of 100 µm width, and (c) Scanning electron microscope (SEM) image of a 50 nm T-gate fabricated at the University of Glasgow [2].

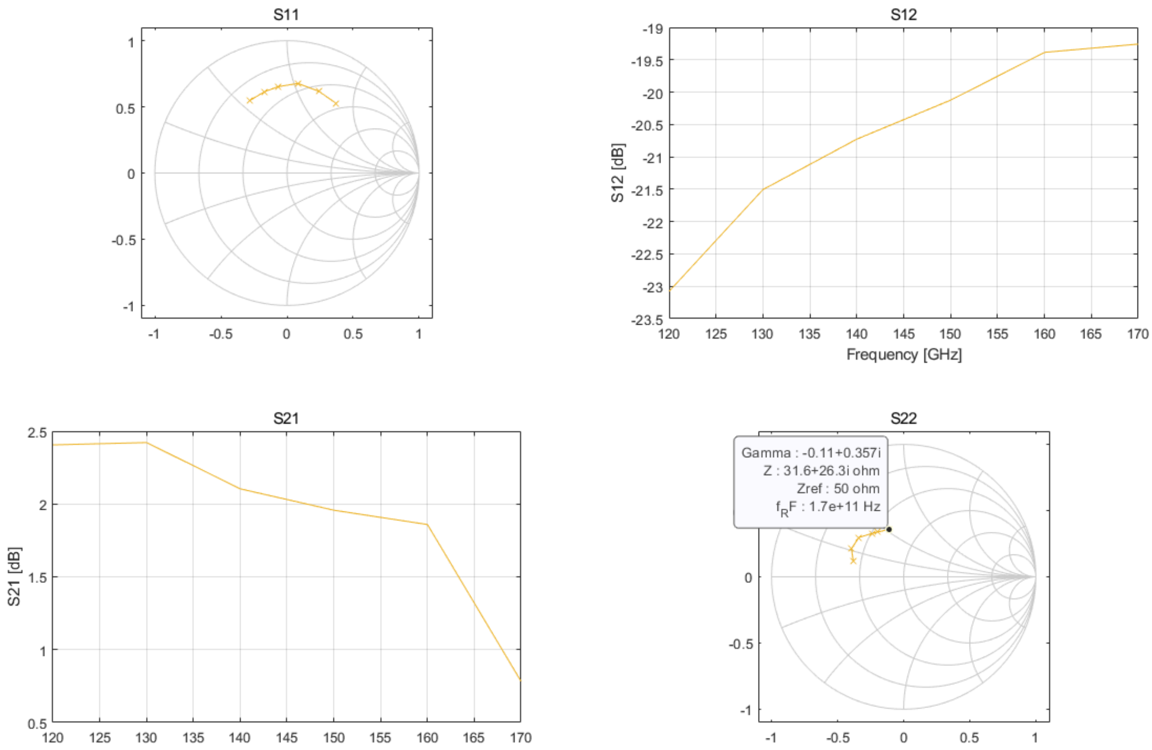


Figure 3. S-parameter of the commercial HEMT when it is biased at with Vg = 0.1 V and Vd = 0.9 V.

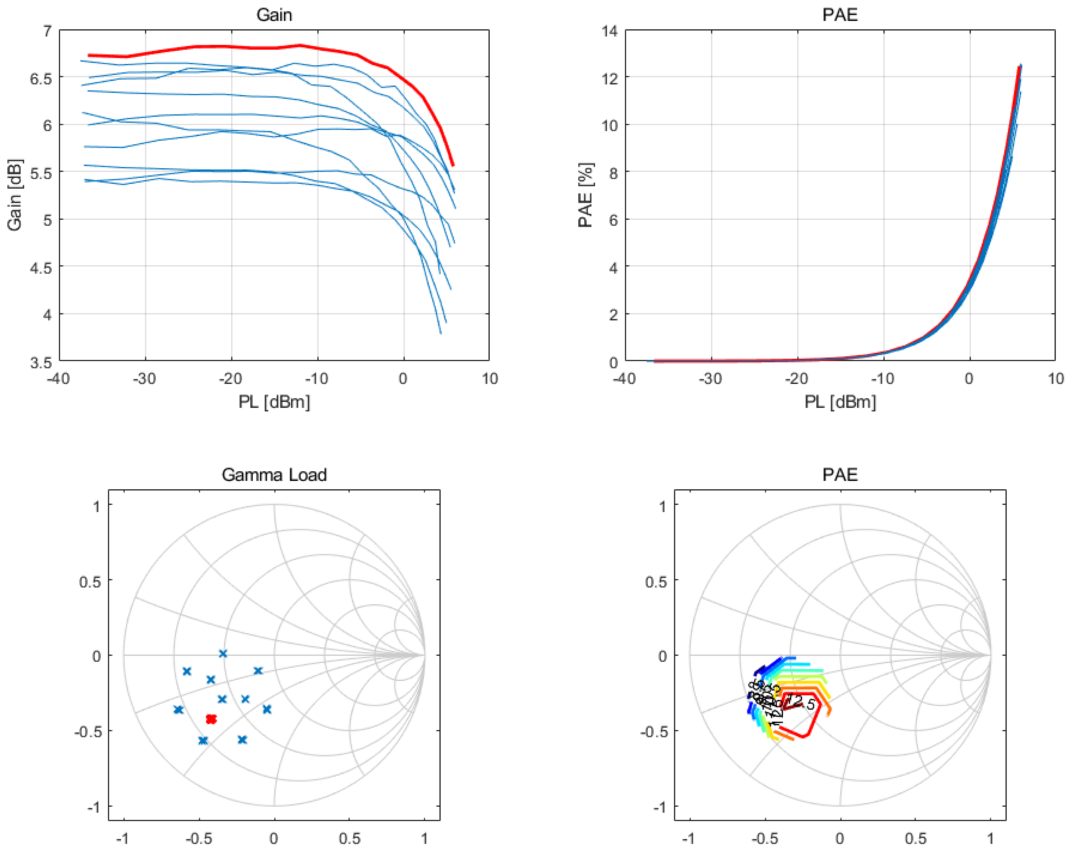


Figure 4. Load pull results at 140 GHz when the HEMT was biased with Vg = 0.1 V and Vd = 0.9 V.

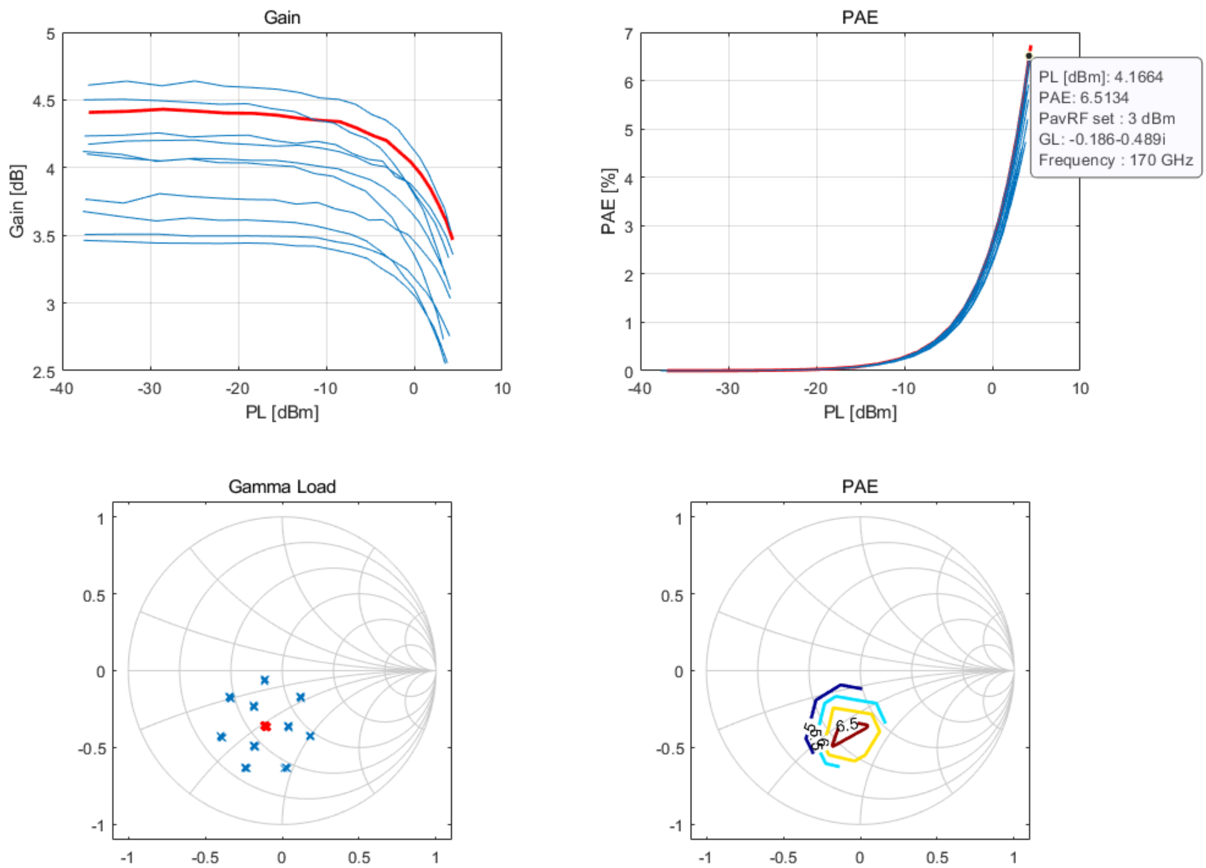


Figure 5. Load pull results at 170 GHz when the HEMT was biased with Vg = 0.1 V and Vd = 0.9 V.

Reference

[1] Wang, J., Xue, L.-Y., Liu, B. and Li, C. (2022) Design of Terahertz InP pHEMT Using Machine Learning Assisted Global Optimization Techniques. In: European Microwave Week 2021, London, UK, 02-07 Apr 2022, pp. 67-70. ISBN 9781665447225 (doi: 10.23919/EuMIC50153.2022.9784068)

[2] Cheng, H., Dhongde, A., Karami, K., Reynolds, P., Thoms, S., Wasige, E. and Li, C. (2022) Reliable T-gate Process for THz HEMTs. UK Semiconductors 2022, Sheffield, UK, 6-7 July 2022.