A Dual Channel SMT Packaged PA for 26GHz 5G

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Abstract

Many mm-wave 5G components are now under development, aiming to address the potential requirements of future 5G systems. The key candidate frequency bands for mm-wave 5G across the globe are becoming evident. In Europe the Radio Spectrum Policy Group (RSPG) has identified the 26GHz Band (24.25 to 27.5GHz) as the ‘Pioneer Band’ for mm-wave 5G. This article describes the development of a dual channel Power Amplifier (PA) housed in a custom laminate SMT package that covers the full 26GHz 5G band. The PA MMIC was designed by Plextek RFI; it offers a gain of 22dB with an RF output power of 26dBm at P-1dB and a PAE of 30%. The laminate packaged dual band component was developed in collaboration with Filtronic with support from the UK’s Compound Semiconductor Applications Catapult (CSA Catapult). Details of the design, implementation and measured performance of both the MMIC and the dual channel packaged component will be presented.

Introduction

Although the formal agreement of the mm-wave bands for 5G will not be finalised until the World Radio Conference in 2019 (WRC-19), a lot of development activity and even some deployment is already well underway in the favoured candidate bands. The bands where development work is already taking place [1] include the FCC licensed bands at 28GHz (27.5 – 28.35GHz), 37GHz (37 – 38.6GHz) and 39GHz (38.6 – 40GHz) in the US, and more recently 24GHz (24.25–24.45GHz and 24.75–25.25 GHz). The favoured European band recommended for the roll-out of mm-wave 5G is the 26GHz Pioneer Band (24.25 to 27.5GHz), which was identified by the RSPG in its Strategic Roadmap Towards Europe, published in November 2016 [2].

The demonstration and development of the first mm-wave 5G systems is progressing rapidly – many trial systems have been produced, and the first operational mm-wave 5G systems are now being rolled out. Component manufacturers are responding to the demands of the market and are developing new innovative products for the key bands. This article describes the design, implementation and evaluation of a 26GHz PA covering the full 26GHz 5G Pioneer Band. It describes the PA MMIC itself and the development of a dual channel SMT packaged component using the MMIC.

MMIC design and implementation

The PA MMIC was designed on a commercially available 0.15µm gate length depletion mode PHEMT process from WIN Semiconductors. It is a three-stage design with an on-chip temperature-compensated power detector to provide a measurement of the transmitted RF output power. A photograph of the MMIC is shown in Figure 1. The die measures 3.5mm x 1.2mm: the length was extended at the input to allow arraying as part of a multi-project mask set. A production version of the die could be realised with a footprint of 3mm x 1.2mm. On-chip bias decoupling components include appropriate low frequency stabilisation networks to ensure broadband unconditional stability.

The output stage of the PA uses two power-combined transistors. Although the available RF output power from a transistor increases as the total gate width increases (more gate fingers and/or wider unit gate width), the available gain at mm-wave frequencies reduces. The choice of optimum transistor size is therefore a compromise between gain and power across the band of interest. As a consequence of this, mm-wave PAs make use of multiple power-combined transistors. In order to deliver the relatively modest power levels targeted in this design (~ 26dBm) only two power combined transistors were required.

Single transistors were used for the driver stage and the input stage of the PA. The transistor sizes were selected carefully to ensure that the driver stages would still operate with good linearity as the output stage started to compress. This is key to ensuring optimum linearity of the complete PA. Frequency-selective loss is incorporated into the matching networks of the first two stages to flatten the gain versus frequency response.

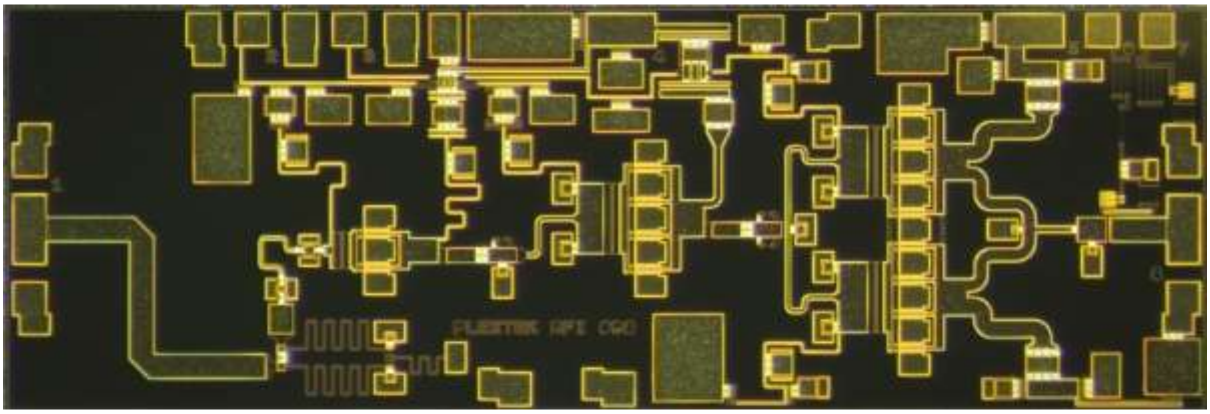

Figure 1: Photograph of the 26GHz PA MMIC

When used in 5G applications the PA will be operated backed-off from compression in order to preserve modulation fidelity; the PA design was therefore optimised for best PAE when operated at 6dB back-off from P-1dB. This entailed extensive load-pull simulations using an accurate large-signal model to determine the optimum quiescent bias point for each transistor, with careful balancing of small-signal gain against efficiency at the backed-off operating point.

A schematic diagram showing the implementation of the temperature-compensated RF power detector is detailed in Figure 2. It comprises a foreshortened directional microstrip coupler with a forward-biased detector diode in the coupled path and a 50Ω termination on the isolated port. A reference diode is included for temperature compensation. This is a replica of the detector diode, including the 50Ω termination and the bias resistor R1. When used in an application, the detected output Vdet and the reference output Vref are pulled up to Vdd via external resistors of several kΩ. When there is no applied RF, both voltages sit at around 2V. When the PA is transmitting RF power, the DC voltage at Vdet reduces as the RF power increases, whereas the reference voltage is nominally fixed. The temperature-compensated power detector output is the difference between Vref and Vdet.

Ground-Signal-Ground (GSG) pads are included at the RF input and RF output ports of the PA to allow accurate RF On- Wafer (RFOW) measurement of the MMIC by probing of the die. It can be seen from the die photograph that the signal pad is wider than the adjacent ground pads. This allows for the attachment of multiple bond wires, when assembled, which reduces the total inductance of the bond wire connection to the MMIC. The size of the signal pad was optimised to provide capacitive compensation to allow a well-matched die-to-PCB transition.

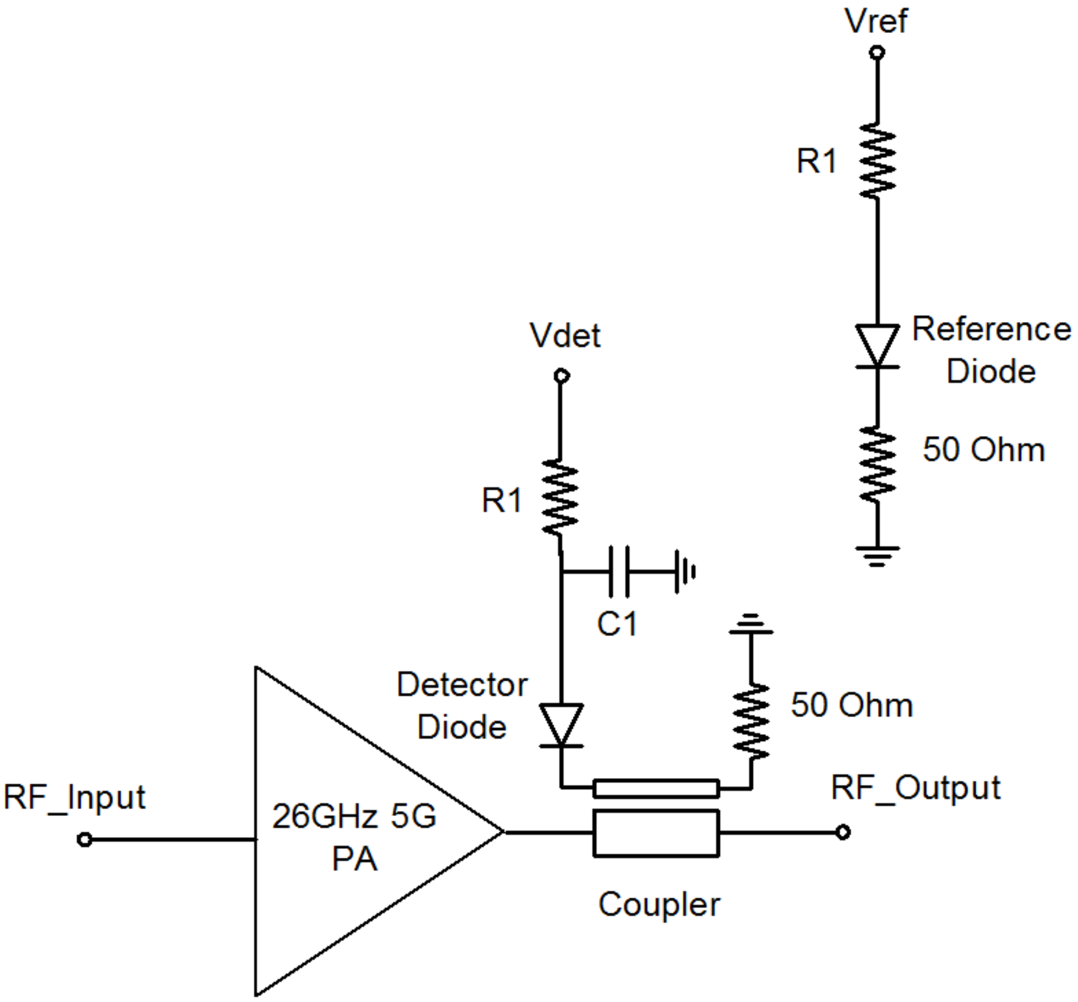

Figure 2: Power Detector at Output of 26GHz 5G PA

Measured performance of the MMIC

The performance of the PA as a bare die was measured using an RFOW probe station. A set of Through-Reflect-Line (TRL) calibration standards was also fabricated along with the PA, to allow calibration to the RF ports of the PA die. The RFOW measured s-parameters of the PA (solid traces) are plotted in Figure 3 together with the simulated gain response (S21), plotted as the dashed trace. Excellent agreement between measured and modelled performance is evident. The quiescent DC bias was 6V Vds with a total current consumption, from all 3stages, of 210mA. The measured gain is 22.5dB ± 1dB from 24 to 28GHz. S11 is < -13dB and S22 < -10dB across the same operating band.

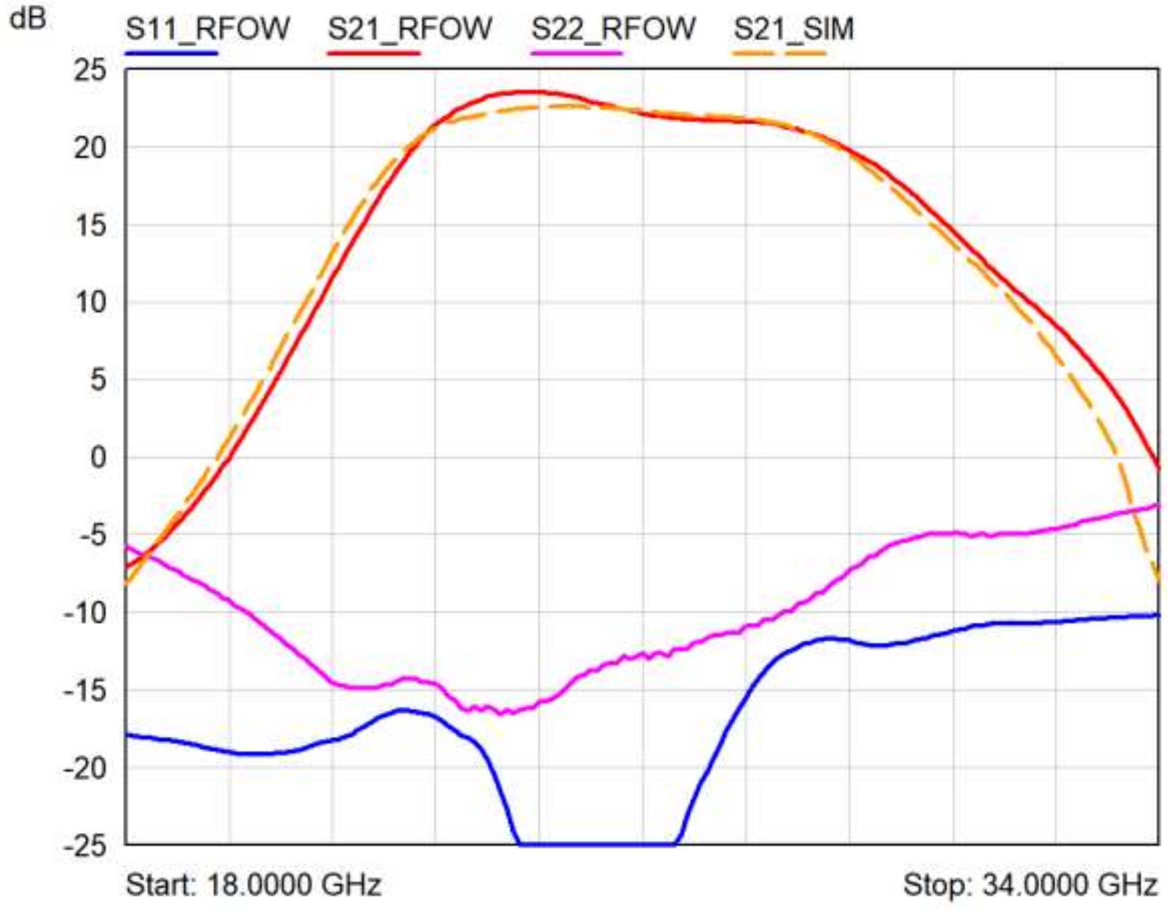

Figure 3: RFOW measured s-parameters of the 26GHz PA MMIC

Figure 4 is a plot of the RFOW measured large signal performance of the PA. PAE and RF output power at 1dB gain compression are plotted, measurement points were made at the top, bottom and centre of the 24.25 to 27.5GHz 5G Pioneer Band. The RF output power at band centre, is around 26dBm at P-1dB with a PAE of 30%. As already indicated, in normal operation 5G PAs will operate backed-off from compression to preserve modulation fidelity. Measurements were therefore also made at 6dB back-off, the measured PAE is included in the plot of Figure 4 and shows a PAE of between 7 and 10% across the band.

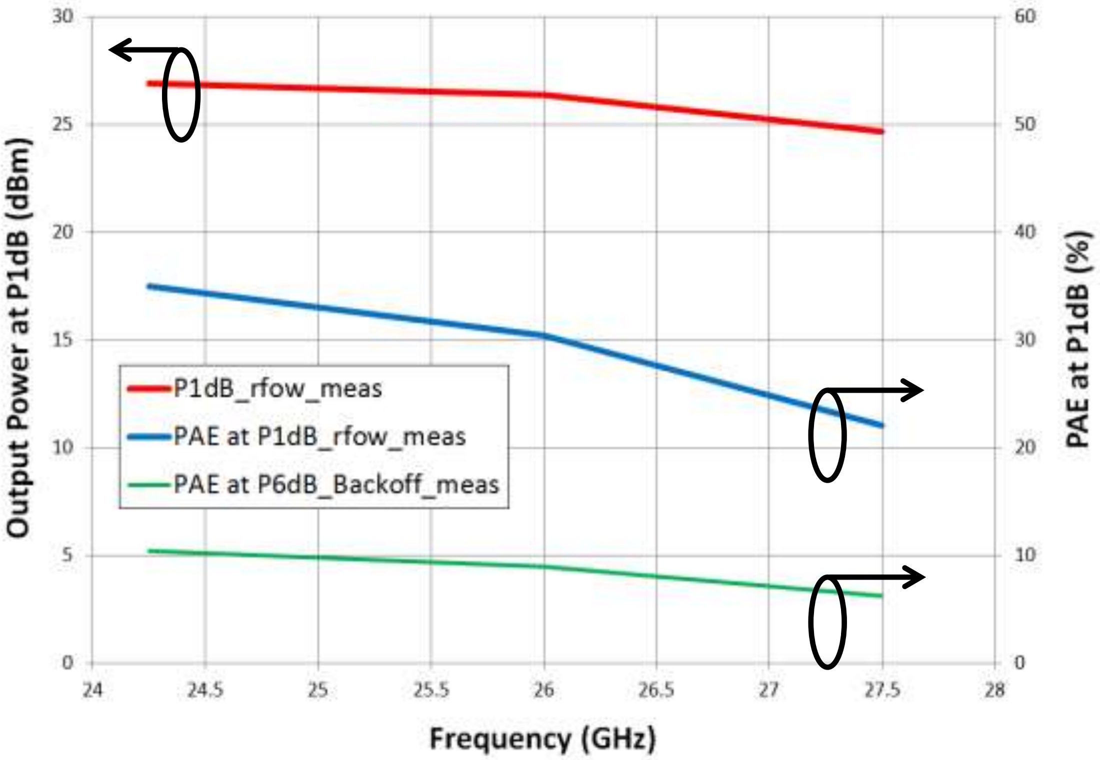

Figure 4: RFOW measured large-signal performance of the 26GHz PA MMIC

SMT package design and implementation

A dual channel, custom laminate SMT package was designed to house two PA MMICs; the resulting functionality is depicted in Figure 5. The package has a standard 32-pin QFN footprint with a 7mm x 7mm body and a solid copper base. It is suitable for solder re-flow attachment using standard volume assembly processes. The packaged component was developed in collaboration with Filtronic, who undertook the package manufacture and assembly, with support from the UK's Compound Semiconductor Applications Catapult (CSA Catapult).

Careful design, EM simulation and optimisation of the internal structure of the custom laminate package was required to ensure a good 50Ω transition from the MMIC to the PCB on to which the package was assembled. The transition model absorbed the bond pads on the GaAs die, the multiple RF bond wires along with the internal package structure and the SMT pad on the PCB. The design was optimised for use with Rogers RO4003 substrate material with a thickness of 0.008" (0.2mm).

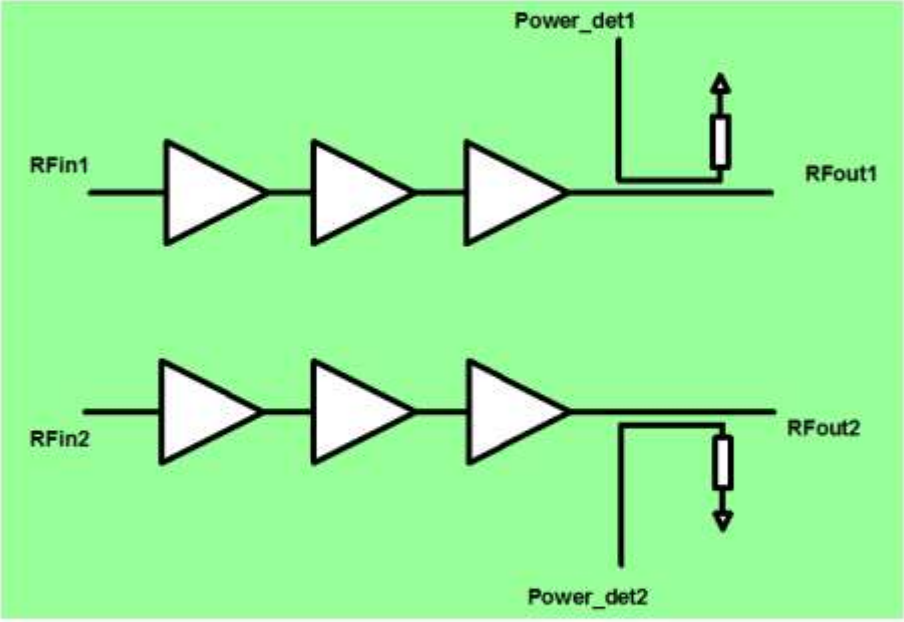

Figure 5: Functionality of the dual channel SMT packaged component

A photograph of one of the packaged dual channel PAs assembled onto an evaluation PCB is shown in Figure 6. The PCB was designed on Rogers RO4003 and assembled onto an aluminium carrier for rigidity and improved thermal performance. A TRL calibration tile was also designed and fabricated using the same approach, to allow calibration to the package ports during evaluation of the packaged part.

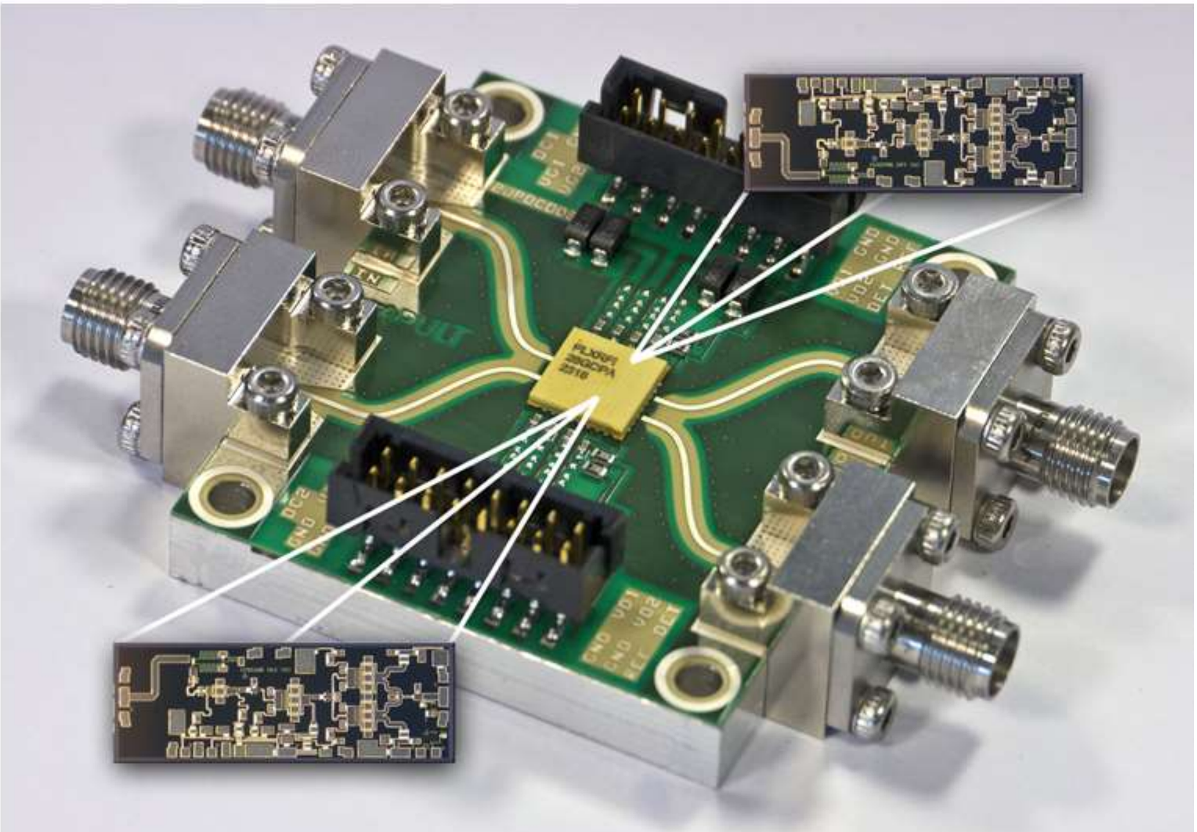

Figure 6: Photograph of dual channel packaged PA assembled onto an evaluation PCB

Measured performance of the SMT-packaged dual-channel PA

The measured data shown below was taken for the packaged part assembled on to the the evaluation PCB. All measured results are referenced to the ports of the SMT package. A plot showing the measured s-parameters of both channels of one dual channel packaged PA compared to the RFOW measured s-parameters of a typical IC is shown in Figure 7. Both channels of the packaged PA have a very similar gain response (S21), which is also very close to the RFOW measured gain (the dashed trace. This agreement between packaged part performance and RFOW performance clearly demonstrates the quality of the die to PCB transition provided by the custom designed laminate package.

The measured S22 of the packaged part is less than -12.5dB from 24GHz to 28GHz. The S22 response actually shows improved performance at the top of the band compared to the bare die, as it was possible to optimise the output transition to allow this. A slight degradation in the measured S11 of the packaged part is evident compared to the bare die but is still less than -10dB.

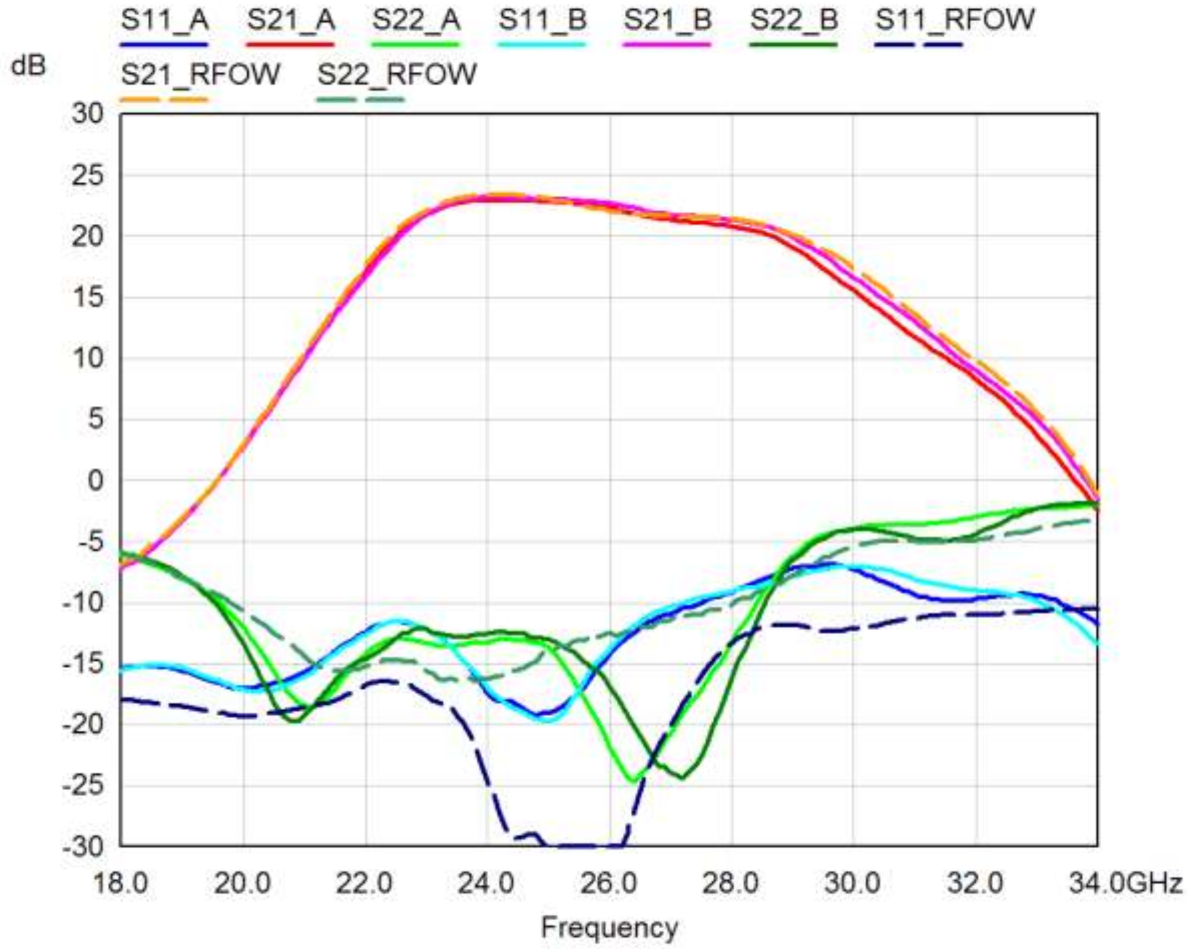

Figure 7: Measured s-parameters of two channels of a package PA compared to RFOW

Measurements were also performed over temperature. The s-parameters of one channel of a typical packaged PA at -40°C, +25°C and +85°C are plotted in Figure 8. Gain variation with temperature for the 3-stage PA is around 0.04dB/°C. Variation in S11 and S22 with temperature can be seen to be modest.

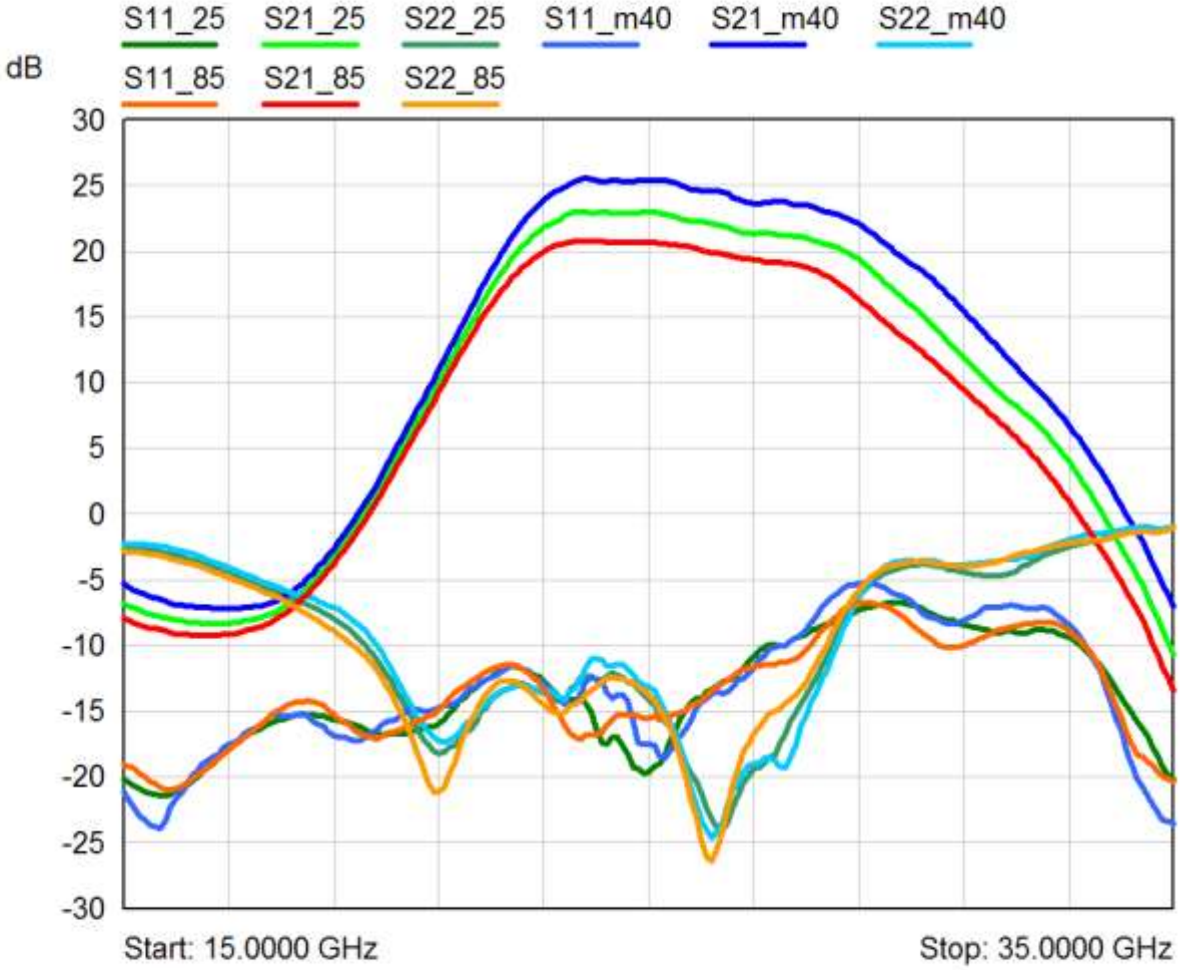

Figure 8: Measured s-parameters of a typical packaged PA over temperature

Figure 9 shows the detected voltage (Vdet – Vref) produced by the on-chip power detector versus RF output power. Three traces are plotted for temperatures of -40°C, +25°C and +85°C. The difference between the three traces is very modest, which demonstrates the effectiveness of the temperature compensation.

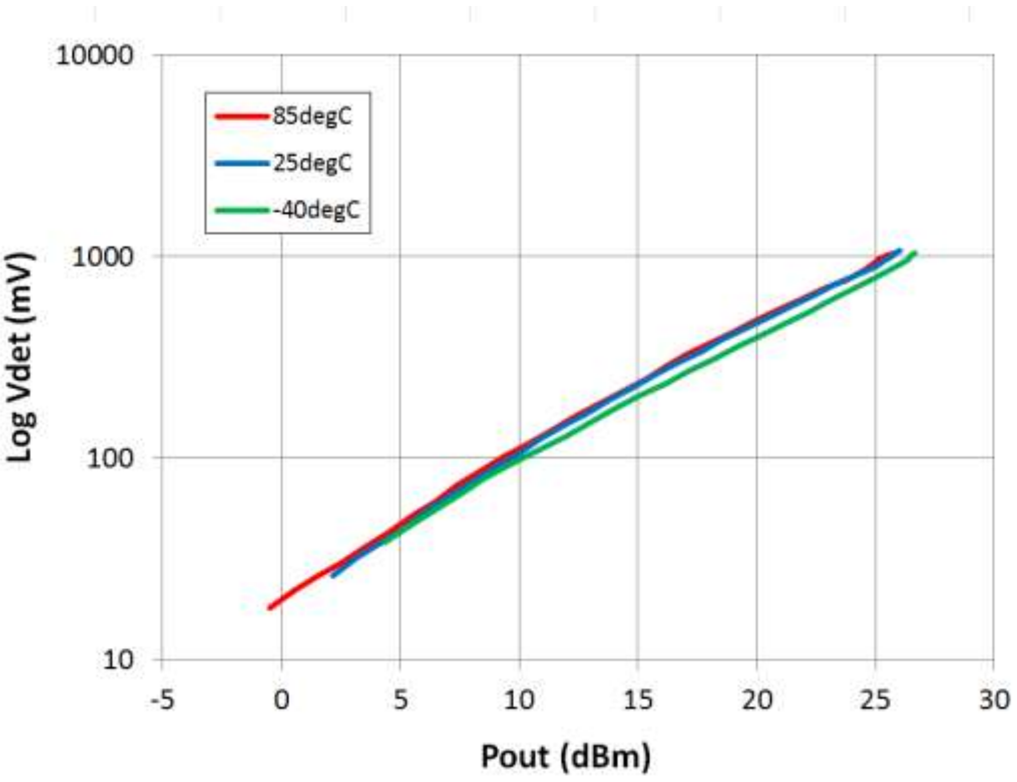

Figure 9: Measured detected voltage versus RF output power at three temperatures

A plot of the measured output IP3 of the packaged part over temperature is shown in Figure 10. At room temperature and -40°C the typical IP3 is around 36.5dBm. At high temperature the IP3 drops by around 1dB, which is due in part to the falling gain of the driver stages with rising temperature.

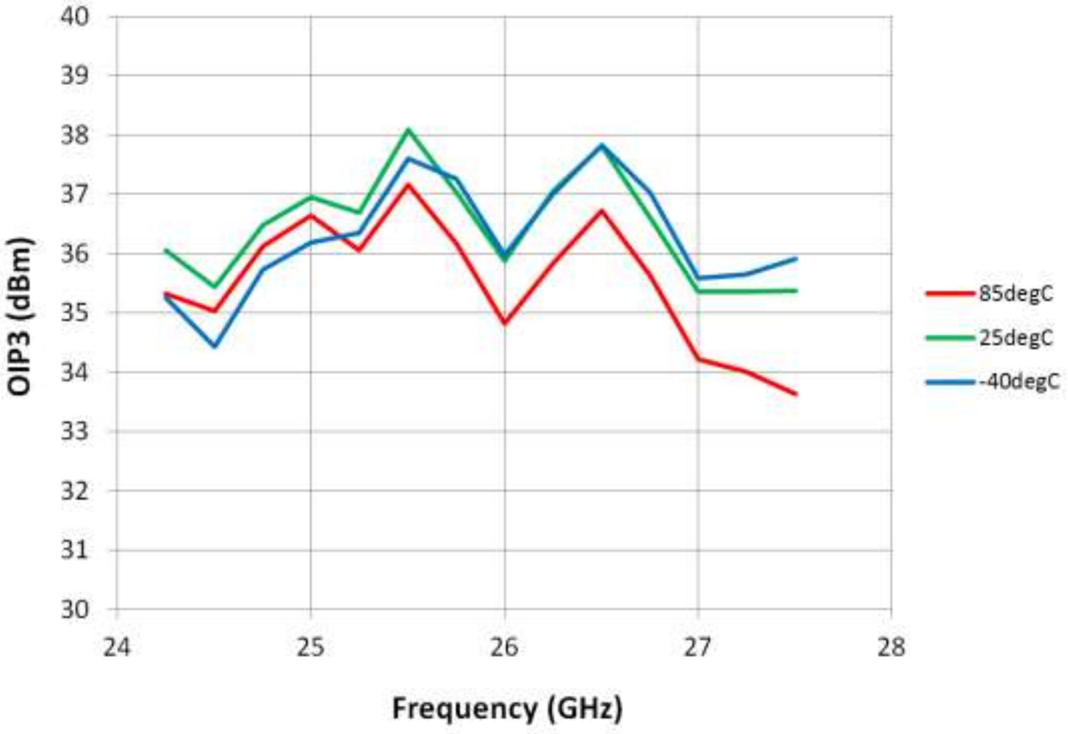

Figure 10: Measured OIP3 versus frequency of a typical packaged PA at three temperatures

Conclusions

As the roll-out of 5G systems progresses the importance of the 26GHz 5G Pioneer Band is expected to grow. This article has described the design and development of a GaAs PHEMT power amplifier IC that covers the full 26GHz 5G Pioneer Band (24.25 to 27.5GHz). It provides a gain of 22dB and a typical 1dB compressed RF output power (P-1dB) of 26dBm with 30% PAE. A dual-channel SMT packaged PA has been developed using a custom laminate packaging technology. Very good RF performance of the package transition (from die to PCB) is demonstrated. A representative evaluation PCB has been designed to allow evaluation of the packaged parts as they would behave in a typical end application. Measured performance referenced to the ports of the QFN package is presented and demonstrates the effectiveness of the package design and manufacture.

References

[1] Components for mm-wave 5G: https://www.plextekrfi.com/mm-wave/mm-wave-5g/

[2] The EU’s Radio Spectrum Policy Group, “Strategic Roadmap Towards 5G for Europe”