50 nm GaAs mHEMTs AND MMICs FOR ULTRA-LOW POWER DISTRIBUTED SENSOR NETWORK APPLICATIONS

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Abstract

We report well-scaled 50 nm GaAs metamorphic HEMTs (mHEMTs) with DC power consumption in the range 1-150 μW/μm demonstrating f_T of 30-400 GHz. These metrics enable the realisation of ultra-low power (<500 μW) radio transceivers for autonomous distributed sensor network applications.

I. INTRODUCTION

Autonomous distributed wireless sensor networks, examples of which include the Speckled Computing Consortium in Scotland [1] or the PicoRadio Project in the Berkeley Wireless Radio Center [2], are widely predicted to have major growth opportunities in the coming years in numerous imaging, safety, biomedical and environmental applications.

In most of these areas, the design challenges are somewhat different from contemporary wireless communications systems in that data rates will be in the order of hundreds of kbits per second and power consumption and size of the sensor node are the key issues [3]. Truly "plug and forget" functionality and the opportunity to embed the sensor nodes into everyday objects or the surrounding environment requires small volume solutions, the majority of which will be occupied by a battery to prolong lifetime.

The Speckled Computing Consortium is currently developing sensor nodes which will be 5mm x 5mm x 5mm in dimension and in addition to various sensors such as pressure, temperature etc. also includes a rechargeable battery, wireless communication (radio including an integrated antenna and optical strategies are being investigated), on-board signal processing and a stripped down microprocessor in the 125 mm^3 volume.

An autonomous sensor node of this volume requires that the majority is occupied by the battery to maximise node lifetime. As a result, the antenna and radio transceiver must fit into an area of 5mm x 5mm and also have low profile to minimise the volume occupied. This would suggest operating at high carrier frequencies to minimise the antenna size, however this results in additional inter-node free space loss and therefore a requirement to consume more power in the radio transceiver to transmit higher power signals and produce higher gain in the receiver chain. Operating at lower frequencies has the advantage of reduced free space losses and therefore lower transmit power requirements, but at the expense of a larger antenna size.

In both cases, an ultra-low power transistor technology is required to optimally utilise the available battery power for inter-node communication.

In this work, the ultra-low power performance of an aggressively scaled 50 nm GaAs metamorphic HEMT (mHEMT) technology is presented, and shown to significantly outperform high performance silicon-based RF CMOS technologies. Indeed, the technology presented here is at least comparable with, and in certain low power bias conditions, outperforms InSb-based solutions, recently acknowledged as an ultra-low power device technology [4]. Finally, we present simulations of the performance of ultra-low power radio transceiver circuits based on the 50 nm GaAs mHEMT technology which suggest that sub-500μW DC power consumption can be easily achieved for on-off-keyed half-duplex inter-node communication, and that by working with carrier frequencies up to 25 GHz, the whole transceiver including integrated antenna, can be fitted into a 5mm x 5mm chip area.

II. DEVICE TECHNOLOGY AND ULTRA-LOW POWER PERFORMANCE

The 50 nm gate length device technology is based on an aggressively scaled, double δ-doped $In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ GaAs mHEMT layer structure shown in Fig 1. Room temperature Hall mobility measurements show a typical electron sheet charge density of $2.31x10^{12}$ cm^{-2} and a mobility of 6470 cm^2/Vs after selective removal of the highly doped $In_{0.53}Ga_{0.47}As$ cap layer. Full process details including the realisation of the 50 nm gate

length T-gates and selective wet-chemical etch gate recess, both shown in Fig 2, are described in [5].

Fig 3 shows plots of h_{21} as a function of frequency at the extremes of DC power consumption in this study. At a drain bias of 0.3V and DC power consumption of 0.6µW/µm, an f_T of 22 GHz is obtained.

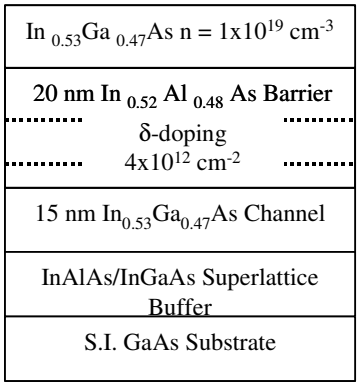

Fig 1 – GaAs mHEMT Layer Structure

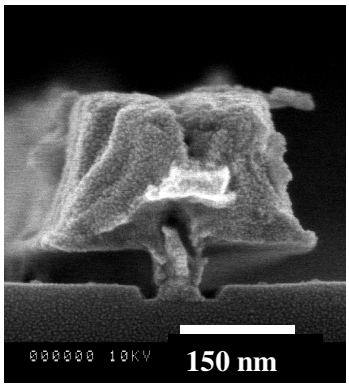

Fig 2 – Micrograph of 50 nm T-gate in Selective Gate Recess

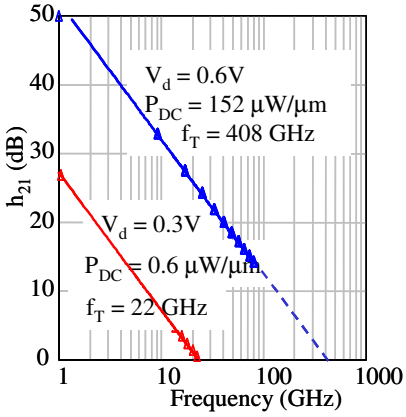

Fig 3 – 50 nm mHEMT f_T for 0.6 and 120 µW/µm DC power consumption

At a drain bias of 0.6V and DC power consumption of 152µW/µm, an f_T of 408 GHz is obtained. At this latter bias condition, the noise figure and associated gain of the devices are indicated in Table 1 for the 2.45 GHz and 24 GHz ISM bands.

Table 1 – Noise Performance of 50 nm GaAs mHEMT technology at 152µW/µm power consumption

Frequency (GHz)	NF_{min} (dB)	G_{ass} (dB)
2.45	0.3	22.5
24	0.7	12.0

Fig 4 compares the f_T/DC power consumption performance of the 50 nm GaAs mHEMT technology with 90 nm (60 nm physical gate length) silicon RF CMOS and 85 nm InSb quantum well transistors (QWT) described in [4].

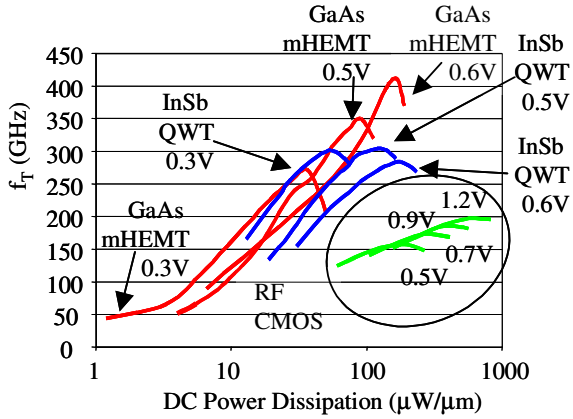

Fig 4 – Comparison of ultra-low power GaAs mHEMT, InSb QWT and Si RF CMOS technologies (from [4])

As can be seen, the GaAs mHEMTs offer significant advantages in comparison with the silicon RF CMOS technology, and whilst having slightly inferior performance for drain bias of 0.3 V (10% lower), outperform the InSb QWT technology for drain biases of 0.5 V and 0.6 V (up to 33% higher).

III. ULTRA-LOW POWER MMIC DEMONSTRATORS

For inter-node separations of less than 1m, as envisioned in the Speckled Computing Consortium distributed sensor network solutions, it is estimated that transmit powers of around –10 dBm will be required. A simple half-duplex on-off-keyed (OOK) modulation strategy is being implemented in which an oscillator at the transmit side is directly modulated with an information stream of up to 200kbits^{-1}. At the receiver side, a number of circuit topologies are being investigated including incoherent reception using a low noise amplifier and diode detector or super-regenerative receivers.

Based on the measured characteristics of the 50 nm GaAs mHEMTs described above, a range of MMIC demonstrators targeted at ISM bands have been designed. By operating at 2.45 GHz, a 5mm x 5mm transceiver solution based on lumped element matching networks can be achieved. Figs 5 and 6 show the simple, single transistor amplifier and oscillator circuit topologies used in this design study. Chip sizes of the amplifier and oscillator are 1.25 x 1.2 mm and 2.3 x 1.2 mm respectively. DC power consumption in both circuits is predicted, by simulation, to be 300 µW. For similarly modest power consumption, the low power performance of the 50 nm GaAs mHEMT technology enables transceiver operation up to 24 GHz, where distributed matching techniques can this time be used to reduce losses associated with lumped matching elements whilst simultaneously meeting the maximum chip area requirements. Figs 7 and 8 show the circuit schematics of the 24 GHz amplifier and oscillator, each of which consume 300 µW DC power. These amplifier and oscillator MMICs are of dimensions 1.0 x 2.5 mm and 2.0 x 1.5 mm respectively.

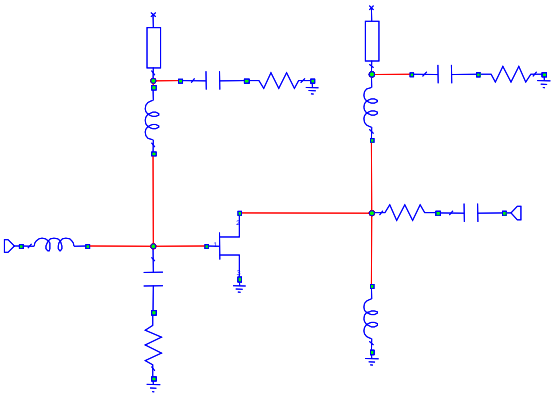

Fig 5 – Single stage 2.45 GHz LNA with lumped element matching

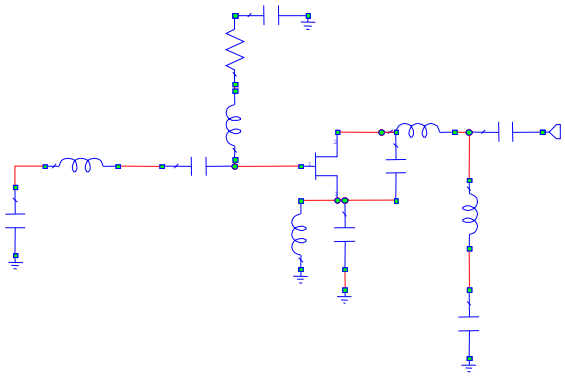

Fig 6 – Single transistor oscillator with lumped element matching

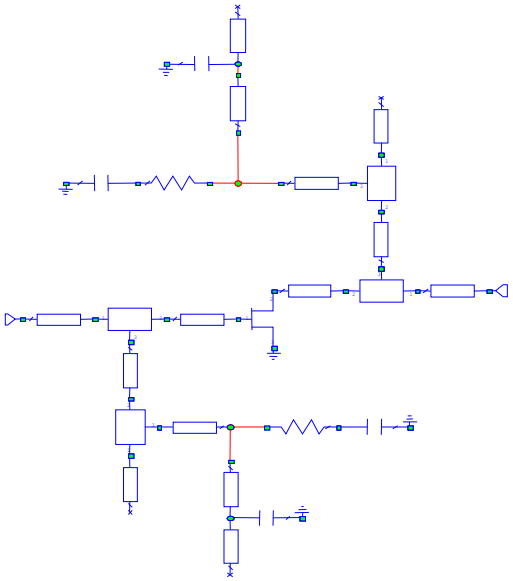

Fig 7 – Single stage 24 GHz LNA with distributed matching

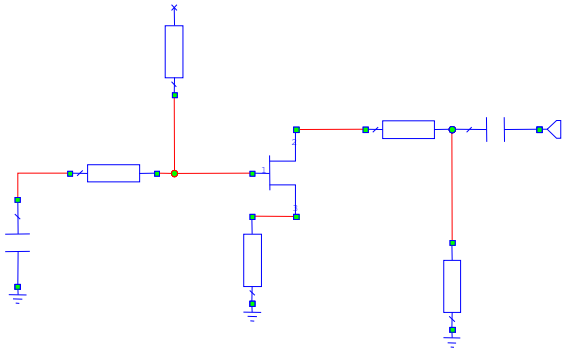

Fig 8 – Single transistor 24 GHz oscillator with distributed matching

The operating frequency, RF performance, DC power consumption and size of the various MMICs are summarised in Table 2.

Table 2 – Outputs of ultra-low power MMIC design study

MMIC	Freq (GHz)	Specification	DC Power (µW)	Size (mm x mm)
LNA	2.45 24.1	Gain>7 dB Match<-6 dB	300	1.25 x 1.2 1.0 x 2.5
Oscillator	2.45 24.1	P_{out} -10 dBm	300	2.3 x 1.2 2.0 x 1.5

IV. CONCLUSIONS

We have demonstrated well-scaled 50 nm gate length GaAs mHEMTs with ultra-low power performance which significantly outperforms RF CMOS and has at least comparable characteristics to InSb QWTs. Further, we have presented the performance of MMICs based on the GaAs mHEMT technology which will enable the realisation of ultra-low power distributed sensor network solutions as ensivaged by the Speckled Computing Consortium.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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