A COMPARISON OF TOPOLOGIES FOR SINGLE-ENDED MILLIMETER-WAVE MONOLITHIC AMPLIFIER DESIGN

S.Nam*, S. Miya, M. Ozaki** and I. D. Robertson***

* Microwave Circuits and Devices Group
King's College, Strand
London WC2R 2LS, UK

** Asahi Chemical Industry Co., Ltd
2-1, Samajima, Fuji, Shizuoka, 416 Japan

Abstract

The performance of five key single-ended monolithic millimetre wave amplifier topologies is compared with design, fabrication and measurements. This is the first such extensive comparative study of the special problems encountered when designing millimetre-wave amplifiers. The five different circuit topologies have been applied to the design of two-stage amplifiers using the same AlGaAs/GaInP PHEMT foundry process in order to arrive at meaningful conclusions. The topologies included are the reactive matching technique, voltage shunt feedback, series feedback, lossy matching and a resonator type topology. Each one has shown its distinctive behaviour at millimetre-wave frequencies. The comparison has been performed with simulations and verified through measurements.

I. Introduction

Since the single-ended amplifier topology is characterised by its simplicity, compact size and low cost it has dominated MMIC low noise amplifier design [1-3]. But the single-ended amplifier is also characterised by its difficulty of obtaining good stability, gain flatness and input/output match over a wide bandwidth. The various well-known amplifier topologies offer different advantages and disadvantages, and the demand of the particular system application will ultimately determine which amplifier is most suitable. Many papers have been published on mm-wave amplifiers [1-2], but direct comparison of the results are difficult due to the varying device technology and device size used. This paper address this issue using both simulations and measured performances. The selected topologies for a comparison for mm-wave monolithic amplifier designs are:-

1) reactively matched amplifier
2) lossy matching amplifier
3)voltage shunt feedback amplifier
4) series feedback amplifier
5) resonator type amplifier

In order to draw direct comparison between topologies, it is necessary to restrict the design conditions. All different amplifiers described in this paper have been designed with following conditions:-

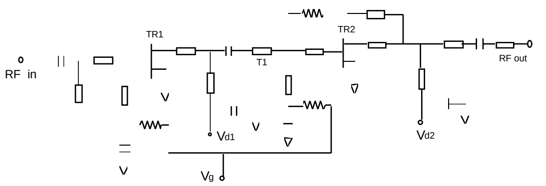
1) Identical PHEMT with 2 x 60 μm gate width and 0.25 μm gate length has been used.
2) All amplifiers have been designed in two stage single-ended form.
3) The amplifiers operate in Ka band.
4) Targets of 13 ± 1dB gain and 10dB input/output return loss have been applied.

Under the same condition by confining as above, amplifier performance parameters will be accurately compared each other.

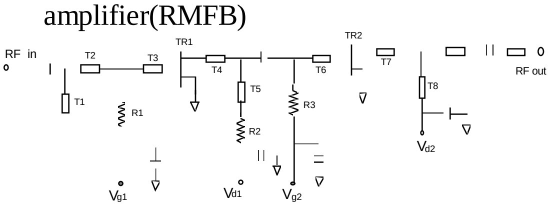
II.Amplifier design and comparisons

The topologies of the amplifier modules are presented in Fig. 1.

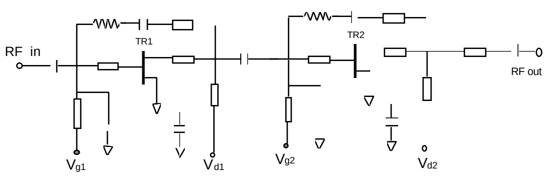
0-7803-4471-5/98/$10.00 (c) 1998 IEEE



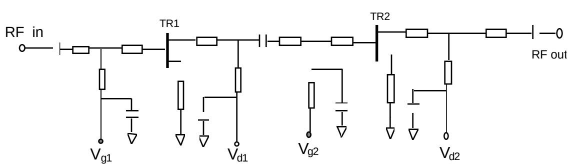
(a) Reactive matching plus feedback matching amplifier(RMFB)



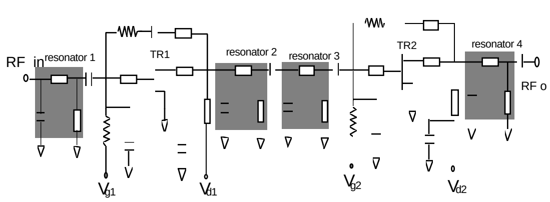
(b) Lossy matching amplifier (LM)



(c) Voltage shunt feedback ampliifer (FB)



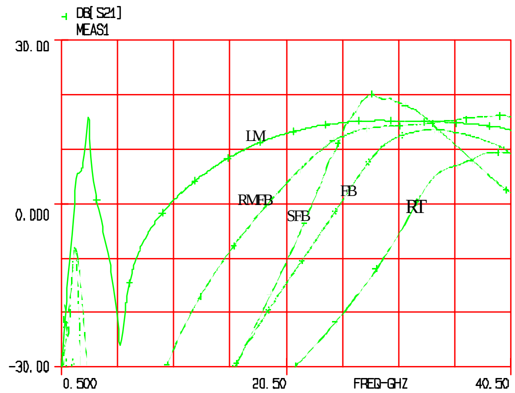
(d) Series feedback amplifier (SFB)



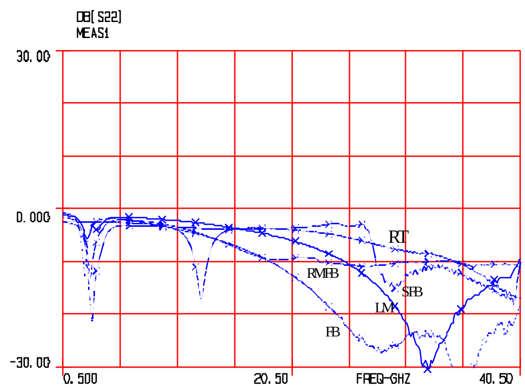
(e) Resonator type amplifier (RT)

Fig.1 The selected topologies (schematics) for the amplifier modules

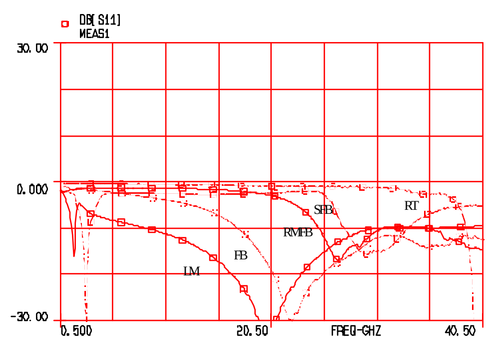
The measured and simulated performances of the five circuits are plotted in Fig. 2 across the frequency range of DC to 50 GHz. As described earlier, noise figure and bandwidth have been optimised with pre-fixed gain and return losses. All designs were performed using HP's MDS^{TM} and all discontinuities corresponding to the layout, for example, bend, T-junction and cross etc, were performed on Sonnet's *em*^{TM}. All five circuits have been implemented on GEC Marconi's H40 PHEMT foundry. All circuit notations referred in this section are shown in Fig. 1, and all fabricated MMICs are shown in Fig. 3.



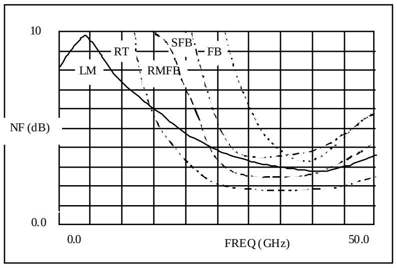
(a) measured gain performances



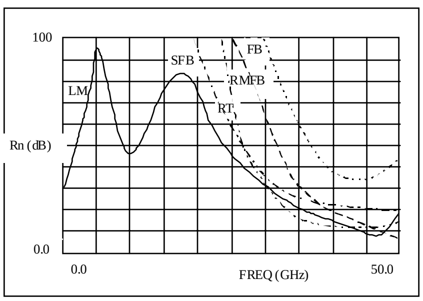
(b) measured output return loss performances



(c) measured input return loss performances



(d) simulated noise figure



(e) simulated equivalent noise resistance

Fig. 2 Measured and predicted performances of the five mm-wave MMIC amplifiers

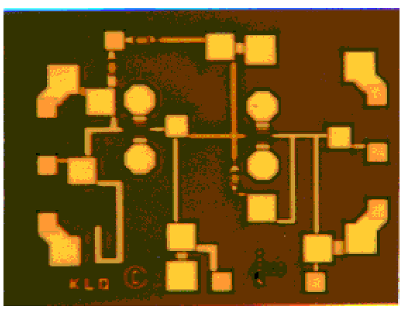
RMFB amplifier *(Fig. 1a) :* The RMFB amplifier (V_g=-0.2 V, V_d=2.1 V and I_d/stage = 23mA) has shown 13 ± 1.5 dB of the gain from 24 GHz to 40GHz with very acceptable input (-12dB) and output (-11dB) average return losses. The amplifier is expected to work well up to 45 GHz with average expected NF of 2.7 dB. The measurements have shown good agreement with predicted results. The results confirm that it is quite stable at all bias condition without any extra elements. This is due to the stabilising resistor[4]. The topology would be a good candidate for achieving a highly stable, high gain amplifiers with wide bandwidth and good noise performances.

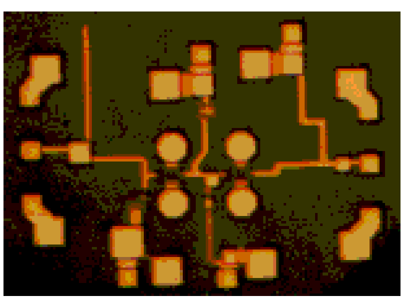
LM amplifier *(Fig. 1b) :* The LM amplifier (V_g=-0.3V, V_d=+2.0V, I_{d1}= 35mA and I_{d2} =25mA) gives wide 3dB gain bandwidth (16 to 40 GHz with average gain of 12dB), average in/out return losses of -16/-12dB. Again, performance over 40 GHz could not be confirmed but the amplifier is expected to work up to 45 GHz or more as simulated. But, a closer look at the output matching shows disagreement with predicted results; S22 below 25 GHz is not acceptable, this is probably because the reactively matched output network was not complex enough to offer broad band matching. With its excellent stability, the purely lossy-matched amplifier would be very suited to wideband applications with reasonably good noise figure.

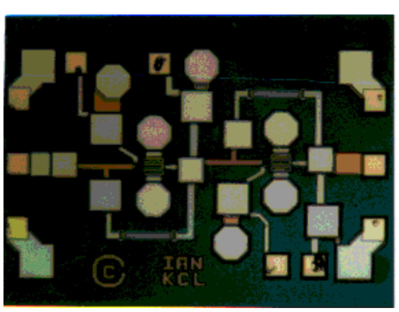
FB amplifier *(Fig. 1c) :* The FB amplifier, biased at V_g=-0.0V, V_d=2.1 V and I_d/stage = 27mA , gives gain of approximately 11.5 ± 1.5dB between 28GHz and 40 GHz with average input and output reflection coefficients of -12dB and -25dB respectively. This topology provides the best results in matching performance. Due to the ability to control gain and stability neatly via the choice of the feedback resistor, this topology is suitable for a wide range of applications, but is not optimum for low noise figure.

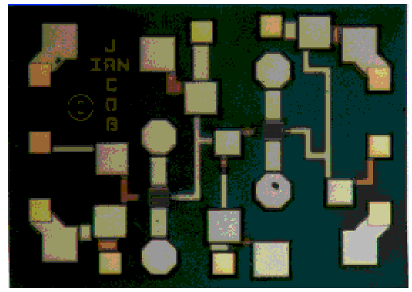
SFB amplifier *(Fig. 1d) :* With the series feedback topology, inserting source inductance can move the noise matching point closer to the power matching point, consequently getting good noise figure with reasonable gain and return losses as well as improving stability [3]. In a practical design, it is necessary to make S_{11}^* equal or close to Γ_{opt} (optimum noise matching point) of the transistor by the careful control of a series feedback to get noise and power matching simultaneously. The advantage of the series feedback amplifier is generally to be able to get good noise performance and stability without sacrifice of gain and return loss. The measurement demonstrates over 12 dB gain from 27GHz to 37 GHz with its peak at 30 GHz and average reflection coefficients input and output, -14dB and -11dB respectively.

RT amplifier *(Fig. 1e) :* Most often, reactive matching is performed using L- or Pi-networks with combinations of inductors and capacitors or series lines and shunt stubs. This simple but effective way is very suitable to achieve a compact and wideband amplifier. However, it should be noted that these matching networks are often difficult to synthesis with realistic element values. The resonator-type matching network shown in Fig.1e has been designed to create a clearly defined band-pass gain response and can be likened to an active filter . The matching networks consist largely of shunt L-C resonators coupled to the active devices. The shunt voltage feedback amplification has been selected due to its high stability. The advantage of this high-Q amplifier design is in obtaining steep out-of-band attenuation, which provides good opportunity to ease the filtering requirements of a subsystem. The measurements of the RT amplifier (V_g=-0.1 V, V_d=2.3 V and I_d/stage = 19mA) proves that the amplifier provides the lowest gain (8 ± 1.5dB) and the narrowest bandwidth (36.5-40GHz) with steep out-of band attenuation and without any resonance at low frequency.









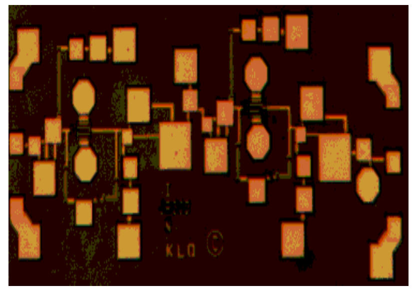


Fig. 3 Microphotograph of the fabricated amplifiers
(a) RMFB (b)LM (c) FB (d)SFB (e)RT

III Conclusions

The 5 amplifier topologies have been extensively investigated before for microwave applications. However, the different design difficulties when operating above 30 GHz have made a fresh comparison of them necessary. To this end, the paper presents the most comprehensive review of MMWIC amplifier design, with a detailed comparison of 5 amplifiers.

Acknowledgements

This work was funded by the Engineering and Physical Sciences Research Council (grant references GR/K27018, 19570, 26998) and Asahi Chemical Industry Co., Ltd. The author would like to acknowledge the assistance of G. Green, M. Brookbanks and A. Dearn at GEC-Marconi Materials Technology Ltd (Caswell).

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