Analysis and Design of Multi-Octave MMIC Active Baluns Using a Distributed Amplifier Gate Line Termination Technique

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Abstract

The analysis and design of a multi-octave MMIC active balun is described in this paper. The technique employed uses the gate-line 'termination' of a distributed amplifier topology as a non-inverting output. Closed-form expressions for the two output signals have been derived. The MMIC prototype has achieved balun operation over 0.5 to 20 GHz with a 10^0 maximum phase error.

Introduction

Baluns are required in key microwave components such as balanced mixers, push-pull amplifiers, multipliers and phase shifters. The need for broadband monolithic baluns is becoming ever greater as MMIC technology advances. A number of different methods have been employed to realise MMIC baluns. These include planar transformer techniques [1, 2], Marchund baluns using multi-layer techniques [3], CPW to slotline transition baluns [4, 5], and recently a technique using simple RF reflection and coupling principles [6]. However, as these techniques all use transmission line concepts, they have a bandwidth limitation at low frequency because on MMIC they cannot be made large enough for good low frequency operation. Active baluns have also been reported which employ pairs of FETs connected in a common-gate common-source configuration [7]. Although good balun performance has been achieved, these techniques again have a bandwidth limitation because the common-gate FETs cause very high attenuation along the input line. In this paper, the analysis and design of an alternative technique is reported which makes use of the gate-line termination of a distributed amplifier [8-12] topology.

Circuit Description

Fig.1 shows the circuit diagram of the technique considered here:

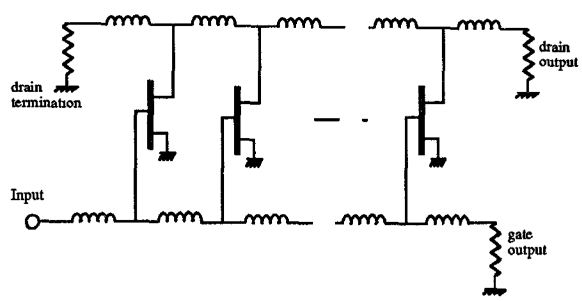

Fig. 1: *Schematic of the Distributed Active Balun*

The basis of the technique is a distributed amplifier in which the gate-line 'termination' is used as an output port. The transistor gate widths are chosen so that the signal from the normal amplifier output is equal in amplitude to the signal from the gate line output. In an ideal common-source FET, the signals are anti-phase at all fundamental frequencies; in a practical FET there is a frequency dependent delay. Multi-octave bandwidth is then readily obtained if the delay in the transistors is compensated for by optimising the cut-off frequencies

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of the gate and drain lines.

Theory

Fig.2 shows a general unilateral FET model. C_{gs}, C_{ds}, r_g and R_{ds} are, respectively, the gate-source capacitance, drain-source capacitance, gate resistance and drain-source resistance of the FET.

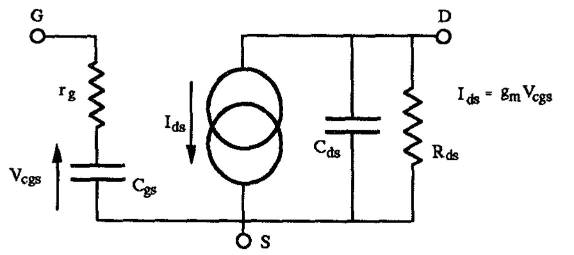


Fig. 2: *General Unilateral MESFET Model*

If we let $Z_2=r_g+(1/j\omega C_{gs})$ and $Z_4=(1/j\omega C_{ds})//R_{ds}$ and then consider signal propagations along the gate and drain lines (see fig.3), we can derive the signals appearing at the drain and gate terminations (V_{doutn} and V_{goutn}), as follows:

$$V_{doutn} = -g_m Z_{od} \Delta_d \Delta_{Z_p} \Delta_{Z_{pp}} \Delta_{Z_{Cgs}} \sum_{r=1}^{n} \exp\{-(n-r)\gamma_d - (r-1)\gamma_g\} \quad (1)$$

$$V_{goutn} = \Delta_{Z_{og}} \Delta_{Z_p} \Delta_{Z_{pp}} \exp\{-(n-1)\gamma_g\} \quad (2)$$

$$\Delta_{Z_p} = \frac{Z_p}{Z_p + \frac{Z_1}{2}} \quad (3)$$

$$Z_p = \frac{Z_2(Z_{og} + \frac{Z_1}{2})}{Z_{og} + \frac{Z_1}{2} + Z_2} \quad (4)$$

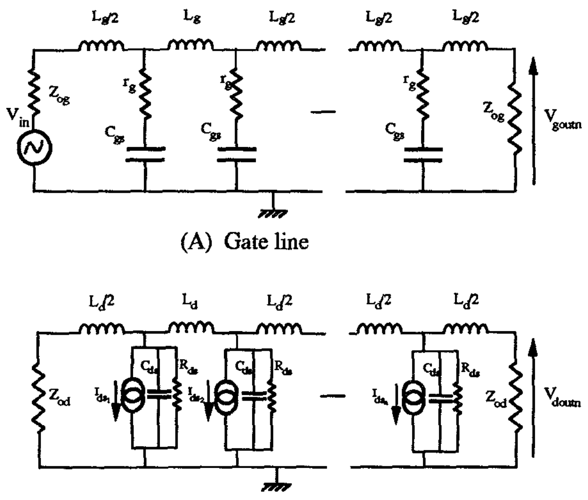
$$\Delta_{Z_{pp}} = \frac{Z_p + \frac{Z_1}{2}}{Z_p + \frac{Z_1}{2} + Z_{og}} \quad (5)$$

$$\Delta_{Z_{Cgs}} = \frac{Z_{Cgs}}{Z_{Cgs} + Z_{r_g}} \quad (6)$$

$$\Delta_d = \frac{Z_4}{2Z_4 + \frac{Z_3}{2} + Z_{od}} \quad (7)$$

$$\Delta_{Z_{og}} = \frac{Z_{og}}{Z_{og} + \frac{Z_1}{2}} \quad (8)$$

Z_{og} and Z_{od} are the image impedances of the gate and drain lines respectively; γ_{og} and γ_{od} are the propagation functions of the gate and drain lines respectively. The amplitude and phase relationships between the two output ports is obtained from (1) and (2).



(A) Gate line

(B) Drain line

Fig. 3: *Gate and Drain Lines*

Fig.4 shows the calculated phase and amplitude response of the balun circuit for a two-section balun, with the transistor gate resistance (r_g) set at 4, 8, and 12Ω and the other FET parameters as follows: C_{gs} = 0.25pF; C_{ds} = 0.05pF; g_m = 23mS; R_{ds} = 400Ω. The results are shown using 50Ω terminating impedances with L_g = 0.2nH and L_d = 0.4nH. It can be seen that the balun technique can easily cover the 0.1 to 20 GHz range, and that the use of low-noise MESFETs or HEMTs would provide low insertion loss.

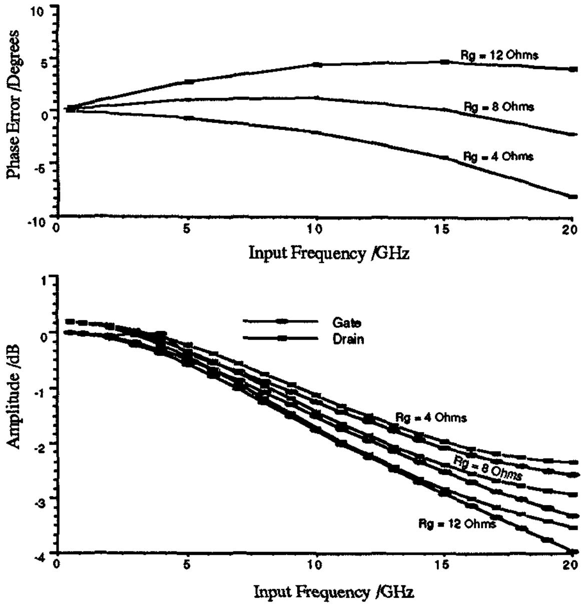


Fig. 4: *Simulated Phase and Amplitude Response*

Fabrication and Measurements

A two-section MMIC balun was fabricated using the GMMT F20 Foundry process, which uses through GaAs via-holes and 0.5μm MESFET gate length. A layout of the chip is shown in fig. 5.

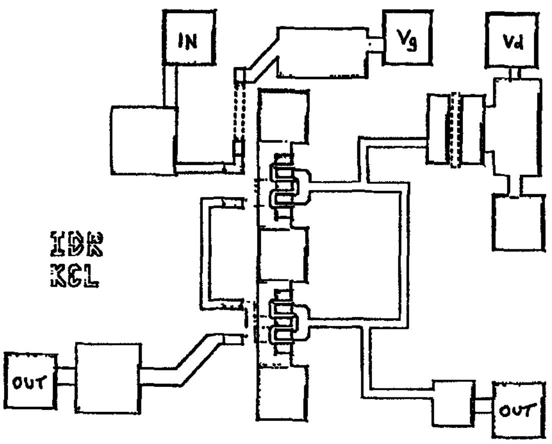


Fig.5: *Layout of the Chip*

The measured phase difference between the two outputs is shown in fig.6, and is very close to 180^0 over 0.5 to 20GHz. The maximum phase error is 10^0. Ripples are observed in the response and these are due to effects of the test fixture.

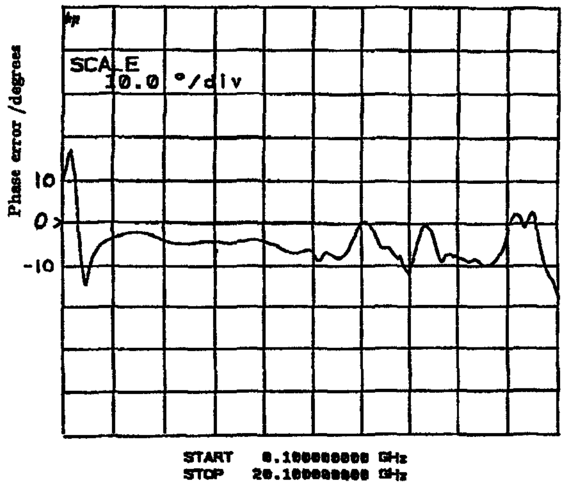


Fig.6: *Measured Phase Response*

The amplitude response is shown in fig.7 and it is clear that although the gain in the gate-line and drain-lines are almost identical, the gain drops-off at high frequencies. This is because the gate line loss increases with frequency due to r_g. However, this is not a major concern since the gain drop-off can easily be compensated for by including a pre-amplifier with a positive gain slope.

Conclusions

The analysis and design of a multi-octave MMIC active balun has been presented in this paper. Closed-form expressions for the two output signals have been derived. An MMIC prototype has been developed which achieved balun operation over 0.5 to 20 GHz with a 10^0 maximum phase error. The gate-line and drain-line amplitude responses are almost identical throughout this band, although the gain drops-off at high frequencies. The bandwidth can be readily extended by using low-noise MESFETs or HEMTs.

Acknowledgements

The authors would like to acknowledge the support of the Engineering and Physical Sciences Research Council and Thorn EMI Electronics Ltd.

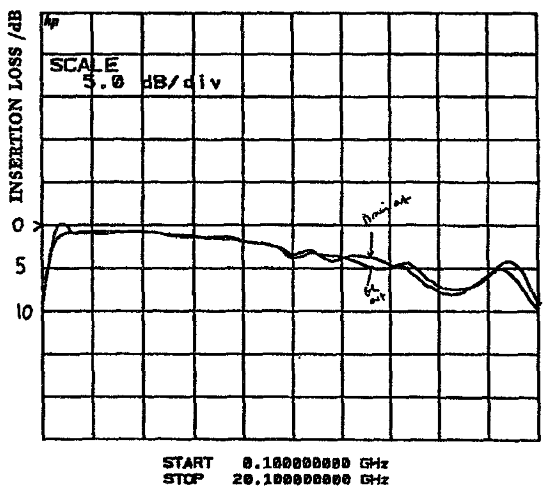


Fig.7: *Measured Amplitude Response*

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