Neutralized Differential Amplifiers using Mixed-Mode s-parameters

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Abstract — **Distributed amplifiers offer very broadband operation, with the promise of a single all-band wireless solution. However, there are a number of distributed amplifier specific issues that have blocked practical implementation in a portable product. One of these is potential instability exacerbated by 20:1 antenna load impedance variation over a very broad frequency range of interest. This paper provides a neutralized differential amplifier implementation supported by mixed-mode s-parameters technology that offers a broadband stability solution for distributed amplifier application. Measurement results of a single section differential amplifier are included using Motorola's CDR1 BICMOS technology.**

I. Introduction

Distributed amplifiers have been used in many broadband small signal applications since their invention in 1935 by Percival. [1] Recent interest in all-band software defined radios (SDR) resulted in distributed amplifiers with very broadband performance and high efficiency. [2] Narrow bandwidth limitations imposed by resonant impedance matching of device input and output shunt capacitance, is overcome by distributing the capacitances over several smaller devices built into a lumped transmission line network. These lumped network sections between distributed devices are designed to provide equal phase shift or time delay allowing inphase signal combining at the device output nodes. [3] A feedback path along with potential instability is built into the basic configuration of a distributed amplifier as shown in Figure.

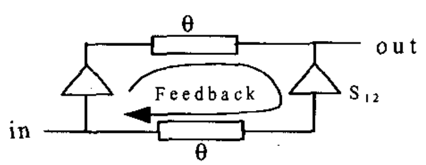

Figure 1. Two section distributed amplifier

However, as the antenna load impedance strays away from the ideal design value there are now a number of devices with a wide variation of load conditions. What this means is, the probability of potential output load condition resulting in unstable operation, is increased by the number of distributed output devices. In the past this required special stability analysis that is labor intensive and requires careful modification to standard linear stability analysis. [4&5] A robust solution would be a unilateral amplifier where the reverse transfer or isolation s-parameter term S_{12} is equal to zero. Using mixed-mode s-parameter analysis, a simple neutralization technique can be implemented to bring the composite reverse isolation term to a very small value over a broad frequency range. [6]

II. Differential – Mixed Mode S-Parameters

Mixed-mode s-parameters represent the complete set of linear signal processing in a four-terminal device. Differential and common mode signal processing types are both supported in a four-terminal device. Differential is defined as equal and opposite voltage across a set of two terminals. While common mode is defined as equal and in-phase voltage across a set of two terminals. The four device terminals are arranged in two pair sets as an input port 1 and output port 2 shown in Figure 2.

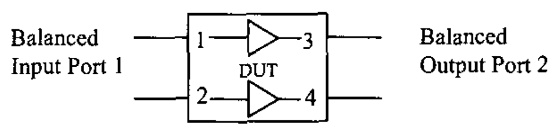

Figure 2. Four-terminal two-port device under test

This two-port four-terminal component of Figure 2, supports pure differential, pure common-mode, cross-mode differential-to-common mode, and cross-mode common-to-differential mode signals. Each of the four signal modes is represented as a 2x2 s-parameter matrix in a 4x4 mixed-mode s-parameter matrix shown in Equation 2. [7] Where dd and cc subscripts identify pure mode differential and common-mode driven /ff measured two port scattering parameters. While subscripts dc identifies common-mode driven with differential port measurements, and subscript cd identifies differential driven with common-mode port measurements.

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$$\begin{bmatrix} b_{d1} \\ b_{d2} \\ b_{c1} \\ b_{c2} \end{bmatrix} = \begin{bmatrix} S_{dd11} & S_{dd12} & S_{dc11} & S_{dc12} \\ S_{dd21} & S_{dd22} & S_{dc21} & S_{dc22} \\ S_{cd11} & S_{cd12} & S_{cc11} & S_{cc12} \\ S_{cd21} & S_{cd22} & S_{cc21} & S_{cc22} \end{bmatrix} \begin{bmatrix} a_{d1} \\ a_{d2} \\ a_{c1} \\ a_{c2} \end{bmatrix}$$ **Equation 1**

Since these are linear parameters representing the complete response of the four-terminal component, one might expect a transformation exists between standard four-port s-parameters and mixed-mode s-parameters. [8]

$$[S]^{mm} = [M][S]^{ss}[M]^{-1}$$ **Equation 2**

Where $[S]^{ss}$ is the 4x4 standard or single-ended four-port s-parameters, $[S]^{mm}$ is the 4x4 mixed-mode s-parameters, and [M] is the transformation matrix,

$$[M] = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$$ **Equation 3**

However, there are some limits in the performance measurement accuracy, associated with mixed-mode s-parameters obtained via the transformation of standard s-parameters into mixed-mode s-parameters. [9]

III. MIXED-MODE NEUTRALIZATION

This transformation from standard s-parameters to mixed-mode s-parameters is expanded in Equation 4. What is shown is the standard s-parameter terms contributing to each of the mixed-mode terms explicitly. Examination of the reverse isolation terms S_{DD12} and S_{CC12} provide clear insight to implementation of a neutralized differential and common-mode amplifier, where these reverse isolation terms will become very small.

$$S_{dd12} = 0.5(S_{ss13} - S_{ss14} - S_{ss23} + S_{ss24})$$ **Equation 4**

For the differential amplifier of Figure 2, implemented with isolated single ended components driven with differential signals, the cross-coupled terms S_{ss14} and S_{ss23} are expected to be very small essentially zero in magnitude. This reduces Equation 4 to the two terms S_{ss13} and S_{ss24}, the reverse isolation across each of the single-ended amplifiers. For identical single-ended amplifiers these two reverse isolation terms should be equal in magnitude and phase and much larger than the cross-coupled terms S_{ss14} and S_{ss23}. These values are dominated by the active device drain to gate parameters and is relatively constant over the operating conditions. Neutralization is accomplished by cross connecting a dummy device from each of the output terminals 3 and 4 to the input terminals 2 and 1. This is shown in Figure 3 with the dummy device gate source terminals connected together. The result is installation of cross-coupled s-parameter terms S_{ss14} and S_{ss23}, that are equal in magnitude to S_{ss13} and S_{ss24} over a broad frequency range. What results when these terms are placed in Equation 4 is a differential reverse isolation of very low value, the amplifier has been neutralized with $S_{dd12} \sim 0$.

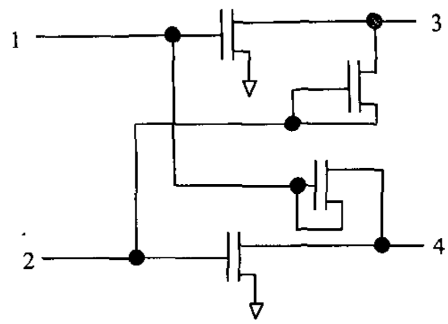

Figure 3. Neutralized differential amp using cross-coupled dummy devices

IV. CONVENTIONAL AND NEUTRALIZED DIFFERENTIAL TEST CELLS

A two-section test structure suitable for on wafer RF probing was generated as shown below in Figure 4. The left half is comprised of two common source nmos devices in a conventional configuration. The structure on the right includes the cross-coupled dummy devices.

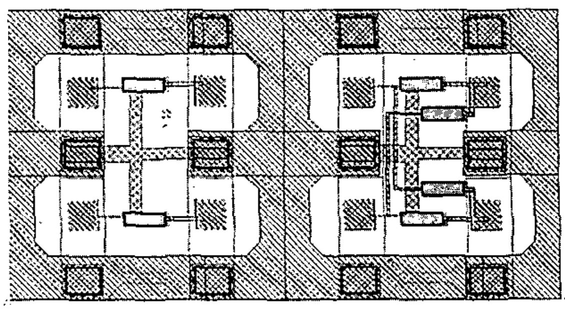

Figure 4. Balanced Stage Test Structure for comparing conventional and cross-coupled dummy device configuration

V. PERFORMANCE

The test structure of Figure 4 was measured using the ATN MMTS Mixed Mode Test Set / HP8753ES combined test system. As can be seen from the graphs of Figures 5 and 6 the smoothed differential reverse isolation (Sdd12) has improved by approximately 25 dB. This improvement is obtained throughout the entire bandwidth of interest and beyond.

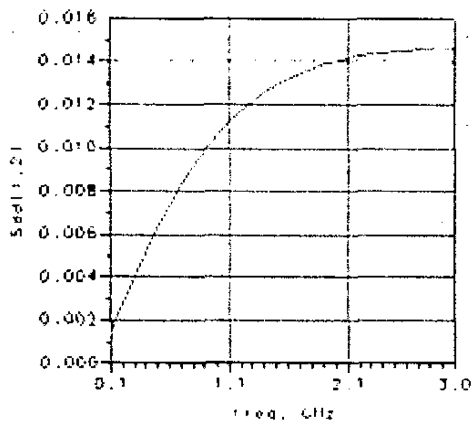

Figure 5. Conventional Balanced Stage Test Structure Differential Reverse Isolation

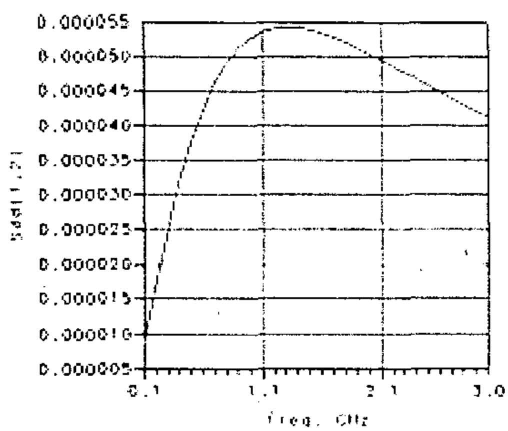

Figure 6. Cross-Coupled Balanced Test Structure Differential Reverse Isolation

VI. CONCLUSION

A broadband neutralization technique has been applied to a differential distributed power amplifier application. This simple implementation is accomplished with dummy nmos devices equal to the active devices. These dummy devices provide matched reverse isolation terms to cancel the differential isolation terms. Neutralization allows a normally stable amplifier design to become unconditionally stable even under large load variations. Standard two-port stability analysis can then be applied to the differential, common-mode, and cross-mode 2x2 mixed-mode s-parameters sub-matrix. The cross-mode signals are expected to be suppressed significantly to insure unconditional stability. However, the common-mode may have unstable operation since the neutralization is not effective on the common-mode signals. Common mode rejection techniques can be used to reduce the common-mode response and insure unconditional common-mode stability.

VII. ACKNOWLEDGEMENT

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