Novel Monolithic Ultra-wideband Unilateral 4-port Junction Using Distributed Amplification Techniques

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ABSTRACT

A novel active unilateral 4-port junction operating over 1 to 20 GHz has been demonstrated in MMIC technology, using distributed amplifier techniques. The circuit has unique unilateral characteristics with a relatively constant insertion loss and high isolation, and could replace isolators, circulators and directional couplers in many ultra-wideband applications.

INTRODUCTION

Isolators, circulators and directional couplers are frequently used where directional separation of signals is required -- such as in TX-RX diplexers, reflectometers and reflection-type phase shifters [1]. However, conventional ferrite isolators and circulators are not suitable for MMIC technology and directional couplers are too large, especially in ultra-wideband applications. This has created interest in active circulators [2,3], but, these offer limited bandwidth. More recently, coplanar waveguide, slotline and FETs have been successfully combined to realize a new class of wideband 3-port unilateral circuit, capable of replacing circulators [4]. In this paper, a novel 4-port unilateral circuit is described which uses distributed amplification techniques and is thus capable of covering an extremely wide frequency range.

CONCEPT

The 4-port junction consists of an active out-of-phase divider feeding an in-phase active combiner [4]. Fig. 1 shows a schematic of the circuit and indicates the four paths of signal flow: $S_{21}=+\alpha$; $S_{41}=-\alpha$; $S_{32}=S_{34}=+\beta$. All other S-parameters are zero for the ideal case. Hence:-

$$S = \begin{pmatrix} 0 & 0 & 0 & 0 \\ +\alpha & 0 & 0 & 0 \\ 0 & \beta & 0 & \beta \\ -\alpha & 0 & 0 & 0 \end{pmatrix}$$

Although the circuit is not a true circulator, its unique unilateral behavior makes many applications possible. Fig. 2 shows the circuit which has been implemented with distributed amplification techniques. Port-to-port isolations are achieved both from the inherent FET reverse isolation, and by the cancellation of anti-phase signals from the output of the active balun.

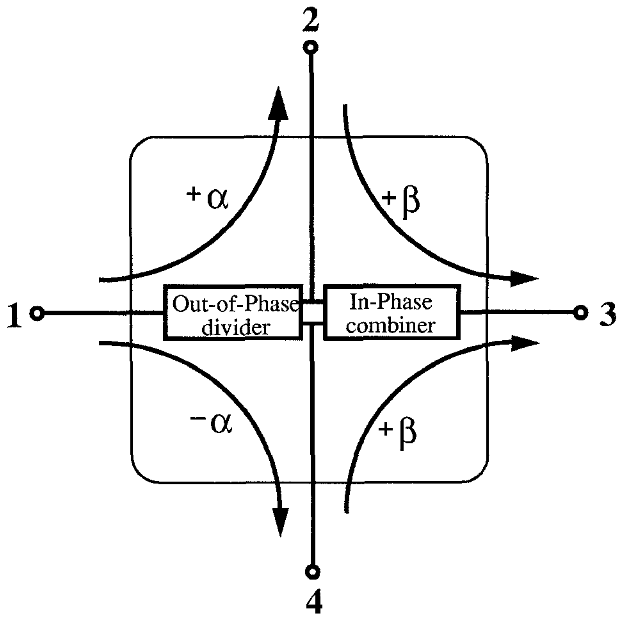

Fig. 1. Schematic of the 4-port Junction, showing the power flow.

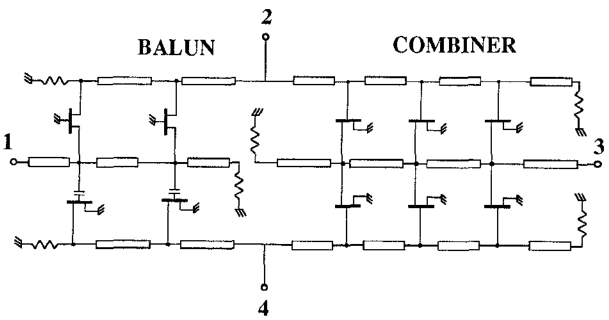

Fig. 2. Circuit diagram of the 4-port junction.

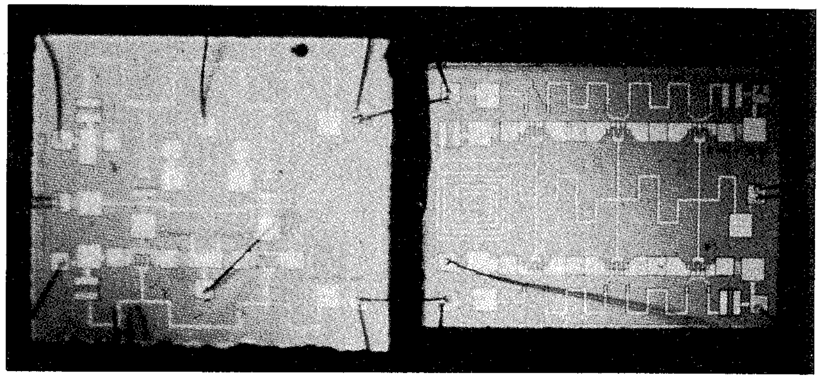

Fig. 3. Photograph of the 4-port junction.

REALIZATION

The circuit has been realized here in monolithic form, by using a distributed common-source/common-gate FET active balun [5], and distributed active combiner [6]. The balun and combiner are separate chips, both designed at King's and fabricated by the GEC Marconi (Caswell) F20 Foundry process. Both the balun and combiner have previously been successfully used in various distributed mixers [7]. The active balun uses two sections; high input line loss caused by the common-gate FETs is found to severely limit the performance improvement gained from using additional sections. The active combiner has three sections, this being constrained by the available chip area. A second design could readily include more sections for improved performance. Both chips incorporate all the necessary decoupling capacitors and bias networks.

To realize the 4-port junction, the two chips were assembled together onto an alumina substrate, as shown in Fig. 3, and measured in a 1"x1" test fixture with SMA connectors. This test fixture leads to significant degradation in the measured response, which can only be corrected for by using a complex de-embedding and renormalization algorithm [8]. However, the measurements presented in this paper have not been de-embedded nor renormalized.

MEASURED RESULTS

Fig. 4 shows the measured insertion loss values. This first experimental prototype exhibits a relatively constant insertion loss of 5dB over most of the band.The measured input and output return loss values were all better than 10dB. Figs.5 and 6 show the measured port-to-port isolations. Apart from a few ripples, resulting from the test fixture, the isolations achieved are all better than 30dB over 1 to 20 GHz, except for $|S_{31}|$: $|S_{31}|$ steadily degrades with frequency, and is found to be critically dependant on the amplitude and phase balance of the output signals from the active balun. The measured phase error of the balun is approximately +/-10^o over 1 to 20 GHz, and the amplitude balance is +/-0.5 dB. Both these could easily be improved upon in a second design, to give the 4-port a much better $|S_{31}|$ response.

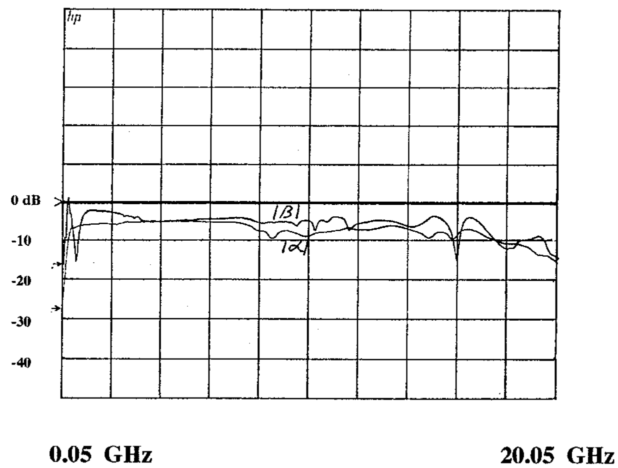

Fig. 4. Measured insertion losses of the circuit.

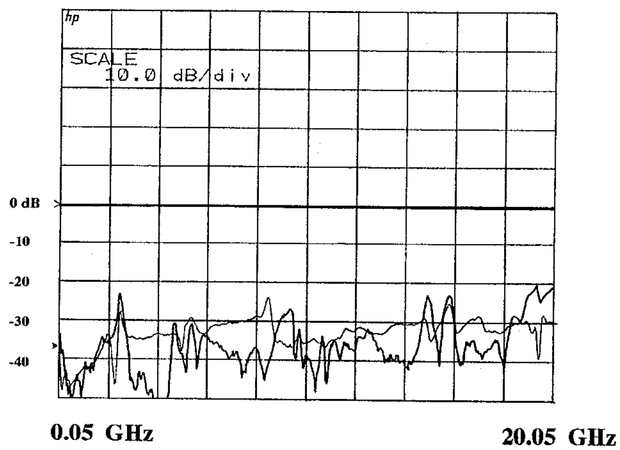

Fig. 5. Measured port-to-port isolations; S13 and S14.

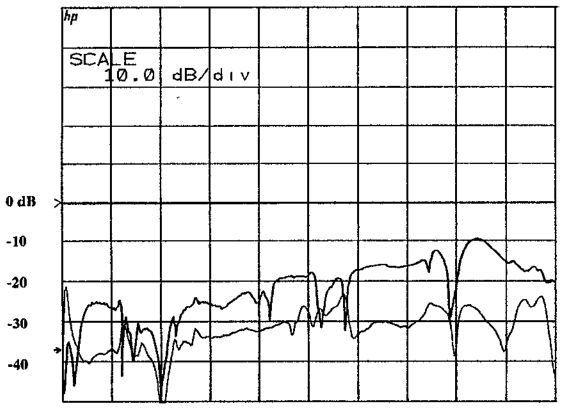

Fig. 6. Measured port-to-port isolations; S31 and S43.

CONCLUSIONS

This novel unilateral 4-port junction is readily amenable to monolithic integration and can be operated over a very wide bandwidth. This prototype operates over 1 to 20GHz, with insertion losses of approximately 5dB and excellent port-to-port isolation. The circuit could be implemented with HEMTs to operate at higher frequencies, with similar isolation performance and with scope for achieving insertion *gain*. One of the key advantages of this active technique, compared to conventional circulators and directional couplers, is that the low frequency cut-off is limited only by the design of the bias networks. With careful design, therefore, and HEMT devices, this distributed 4-port junction could be expected to operate from tens of MHz to well over 40 GHz. The circuit could find applications in many ultra-wideband applications, such as TX-RX modules, reflection-type phase shifters [9] and measurement systems.

ACKNOWLEDGEMENTS

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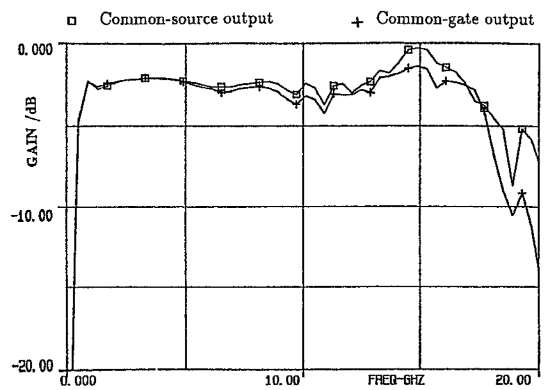

Fig. 7. Frequency Response of the Active Balun (not de-embedded).

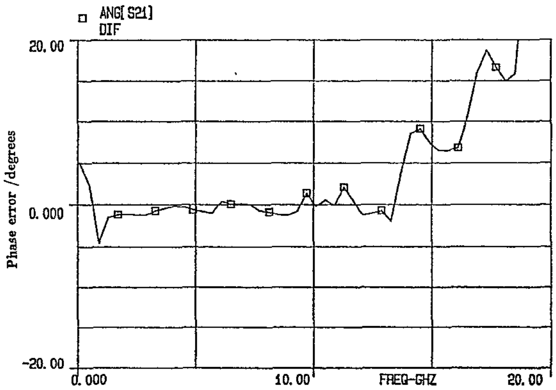

Fig. 8. Phase-Split Performance of the Active Balun.

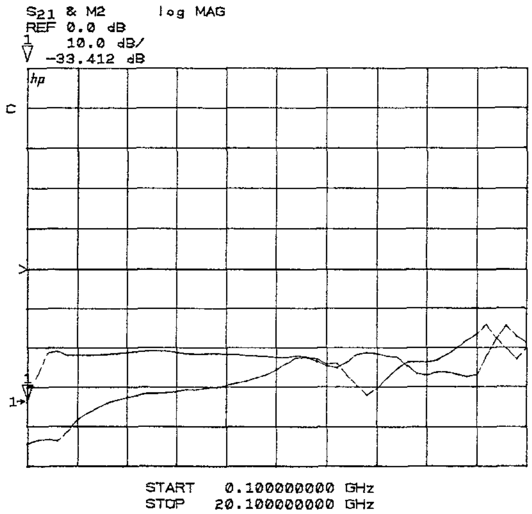

Fig. 9. Output Port Isolations of the Active Balun.

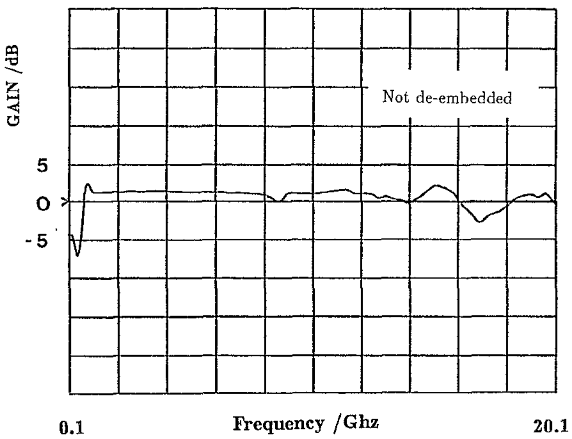

Fig. 10. Frequency Response of the Active Combiner.

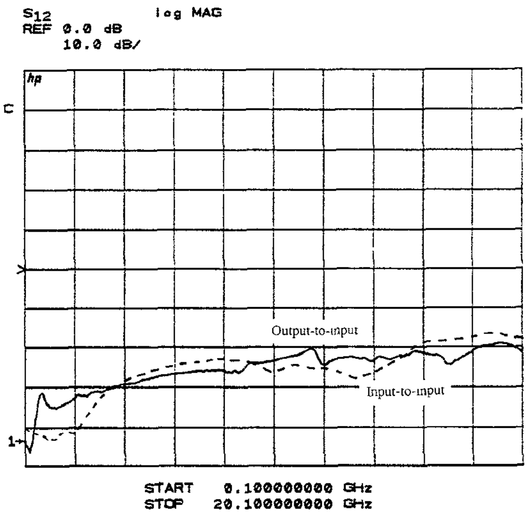

Fig. 11. Port-to-port Isolations of the Active Combiner.