COMPACT MULTI-STAGE SINGLE-ENDED AMPLIFIERS FOR S-C BAND OPERATION

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Abstract - Design and fabrication of compact multi-stage single-ended feedback amplifiers operating from 2 - 8 GHz are discussed. The nominal gains are 22 dB in the three-stage unit and 30 dB in the four-stage unit. Measured maximum VSWR's do not exceed 1.9:1. Noise figures, although not optimized, were below 7.6 dB and 8.4 dB, respectively.

Wide-band multi-stage amplification is generally accomplished by means of balanced amplifier techniques making use of hybrid couplers. The results are flat gain response and low reflection losses. In contrast, cascading of conventional single-ended modules for broadband applications is severely limited by high reflection losses. However, these problems can be easily overcome by employing feedback techniques. [1] [2] [3] [4] Due to the fact that the balanced amplifier requires twice the number of transistors of his single-ended competitor, the low VSWR single-ended approach is of great economical interest. Another very important asset is its smaller size.

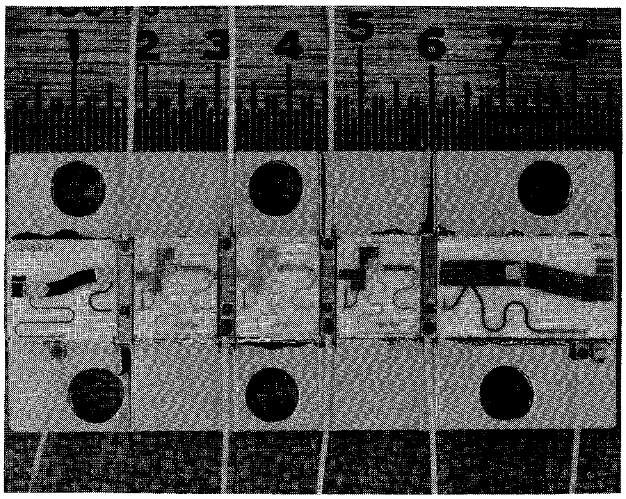

Fig. 1 Four-stage single-ended amplifier brazed to common carrier.

This paper describes the design and performance of compact single-ended multi-stage amplifiers operating from 2 GHz to 8 GHz. Fig. 1 shows the photograph of a four-stage unit consisting of four GaAs FET's located between five substrates brazed to a common carrier. The carrier dimensions are .845 x .390 inches. The substrate farthest to the right contains the input circuit and the input section of the feedback amplifier circuit. It is followed by three identical substrates that each comprise the output portion of the feedback amplifier module, the interstage matching network and the input section of the following amplifier module. The substrate farthest to the left contains the feedback amplifier's output circuit and the output matching network.

The schematic of the multi-stage amplifier showing its main elements is presented in Fig. 2. The diagram illustrates four basic functions: the input matching, the actual amplification, the interstage matching and the output matching. As described earlier, these functions are served by only three different substrate types, regardless of the number of amplifier stages. Different stages may require different amounts of feedback for optimum gain flatness and low reflection loss at the amplifier's input and output port. For this purpose, two different resistors, R_{FB} = 350 and 400 ohms, are provided on the interstage substrates through deposition of a 400 ohm tantalum-nitride resistor with a 350 ohm tap. The input substrate contains a 175 ohm or 200 ohm resistor. The input and output circuits are very simple and designed to provide lower reflection losses, especially over the middle and upper portion of the frequency band. Interstage matching and dc biasing is accomplished by the interstage-matching network, while the output circuit serves similar functions at the amplifier's output port.

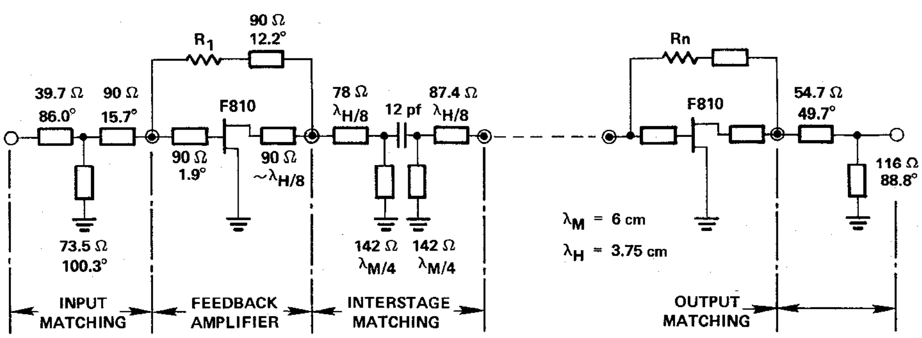

Fig. 2 Circuit diagram of the multi-stage single-ended feedback amplifier (electrical lengths at f = 5 GHz).

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Significant reductions in overall length of the amplifier were realized by employing a simple T-network for interstage matching and biasing. It was accomplished by directly matching the output impedance of the preceding stage to the input impedance of the following stage. This technique deviates from the more common approach of matching the output impedance of one amplifier module and the input impedance of the following module as closely as possible to 50 ohms. The resulting substrate has a mechanical length of .115 in. Electrically, the interstage matching is basically accomplished by a quarter-wavelength transformation at 8 GHz divided into two $\lambda/8$-steps with slightly different impedances. It is supported by two identical short-circuit shunt stubs resonating at midband. The shunt stubs are separated by a 12 pF dc blocking capacitor and serve also for dc-biasing.

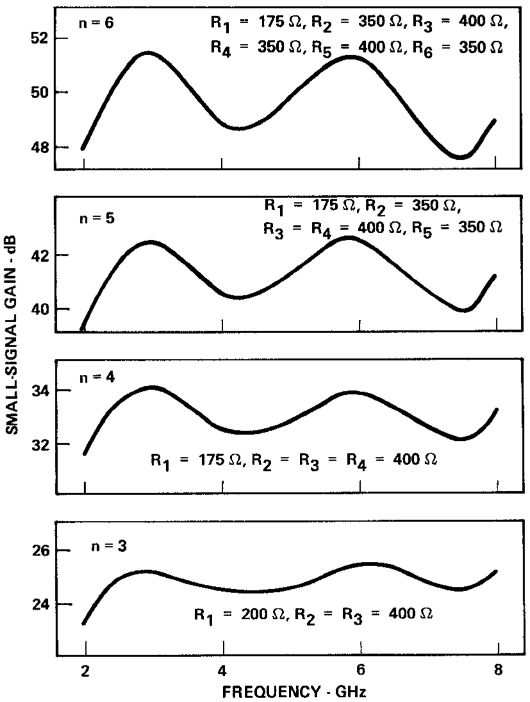

Fig. 3 Computed small-signal gains of multi-stage single-ended amplifiers with n stages (assuming lossless circuits).

The computed gains of four n-stage amplifiers with n = 3, 4, 5 and 6 are plotted in Fig. 3. The feedback resistors of their individual amplifier stages have been chosen for optimal gain flatness. The computed maximum reflection coefficients across the 2 - 8 GHz frequency band are between .23 (n = 6) and .27 (n = 3) for the input and between .21 (n = 6) and .24 (n = 3) for the output terminals, depending on the number of amplifier stages. They decrease with increasing n. The computed minimum reverse isolation increases from 49.6 dB for n = 3 to 100 dB for n = 6 with approximately 16.6 dB isolation per stage. All amplifiers are unconditionally stable.

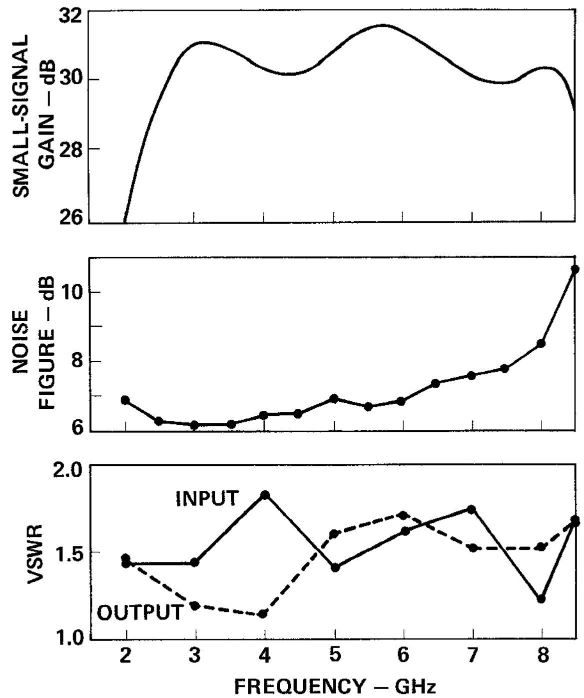

Fig. 4 Measured performance characteristics of the four-stage amplifier (V_{DS} = 4V, $I_{DS\ (aver.)}$ = 84 ma, $g_{m\ (aver.)}$ = 56 ms).

The measured values of small-signal gain, noise figure and VSWR of the four-stage amplifier are plotted in Fig. 4. The agreement between computed and measured small-signal gain is good except for the sharp drop occurring below 2.6 GHz. Input and output VSWR's do not exceed 1.9:1 which agrees well with computed predictions. Even though no attempt was made to improve the noise figure, its maximum value was 8.4 dB across the 2 - 8 GHz band.

The GaAs FET used in the experiment is the WJ-F810 which has been described in the literature. [2] [3] The substrates were made from .025 in. thick alumina. The overall length of the four-stage amplifier as shown in Fig. 1 is .845 in., while the width of the circuits is .140 in. Every additional gain stage adds .140 in. to the length of the amplifier. The feedback resistor sequence of the actual amplifier was R_1 = 230 ohms and $R_2 = R_3 = R_4$ = 400 ohms.

Measured small-signal gain, noise figure and VSWR of our three-stage amplifier are plotted in Fig. 5. Starting at the input, the actual feedback resistor sequence was R_{FB} = 190, 470 and 360 ohms. A minimum gain of 20 dB was measured across the two octaves bandwidth, i.e., 2 - 8 GHz. The maximum VSWR's of this .705 in. long unit were 1.42:1 for the input and 1.8:1 for the output port, while the noise figure did not exceed 7.6 dB. A photograph representing the first iteration of the three-stage amplifier with a choice of five different feedback resistors is shown in Fig. 6.

As demonstrated by the performance of the two described examples, broadband amplification by multi-stage single-ended amplifiers is entirely feasible and has proven to be a very compact and economical approach.

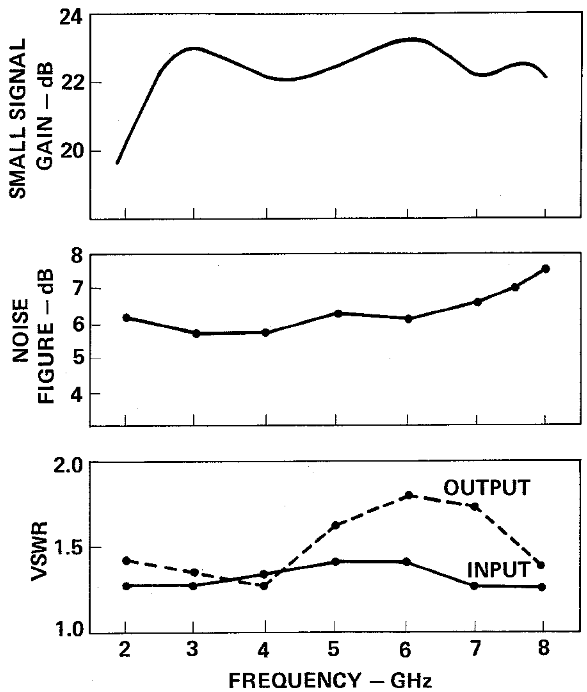

Fig. 5 Measured performance characteristics of the three-stage amplifier (V_{DS} = 3.5 V, $I_{DS\ (aver.)}$ = 75 ma, $g_{m\ (aver.)}$ = 53 mS).

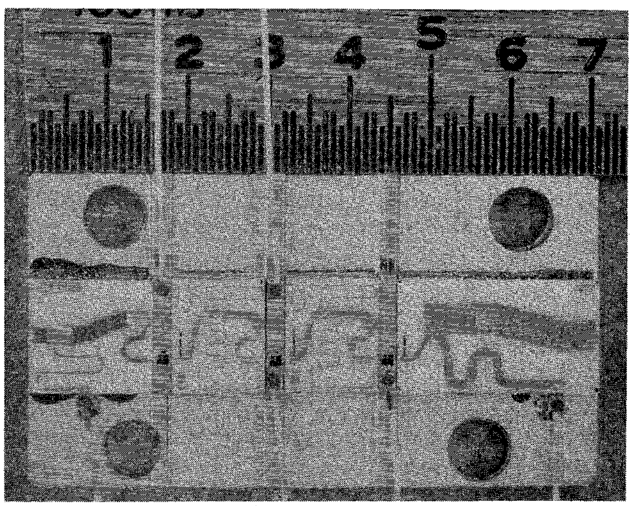

Fig. 6 Three-stage single-eneded amplifier brazed to common carrier (1. iteration).

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