A NOVEL TECHNIQUE FOR MEASURING SMALL SIGNAL S-PARAMETERS OF AN RF/MICROWAVE, TRANSISTOR, POWER AMPLIFYING STAGE FOR USE IN POWER AMPLIFIER STABILITY ANALYSIS

Glenn Collinson and Marty Jones

Texas Instruments Ltd. Bedford, England. MK41 7PA
Texas Instruments Inc. PO Box 665474, Dallas. TX, 75265

ABSTRACT

A novel measurement method is described which enables the full small-signal s-parameters of an RF/Microwave transistor to be measured whilst it is simultaneously driven and optimally tuned at a higher frequency as an efficient, class B or class C power amplifying stage. This capability allows a classic, small signal, stability analysis of power amplifiers to be performed across frequencies below the power amplified carrier where parametrically pumped, subharmonic oscillations are often a problem. Measured s-parameters of a GaAs HBT transistor operating as an efficient, harmonically tuned, class B, PA stage at 870MHz are presented across the frequency range 50-700MHz. Analysis of these results shows the presence of negative resistance in the base and collector that is induced by the carrier.

INTRODUCTION

Small signal s-parameters have limited use in the design of RF/Microwave Power amplifiers. In particular it is very difficult to make accurate predictions of the stability of such circuits from the small signal data alone. This paper presents a possible solution to this design problem by outlining a novel method to measure the full small-signal s-parameters at frequencies below the power amplified signal of a transistor that is operating as it would in a power amplifier circuit.

The ability to measure s-parameters of the device in this way could be of great use in the understanding and control of the stability of power amplifiers in the frequency range where parametrically pumped subharmonic-type oscillations are often a problem [1,2,3,4].

As well as describing two possible set-ups for this measurement, an example is given of the resulting s-parameters over the frequency range 50 to 700MHz of a GaAs HBT transistor that is operating as a highly efficient (75%PAE) power amplifying stage at 870MHz.

The test set allows the s-parameters to be measured for the case where the HBT is simultaneously power amplifying in exactly the environment that it needs for most efficient operation:

- class B bias with a small quiescent current,
- input matched at 870MHz for minimum reflected power
- output matched for maximum efficiency at 870MHz,
- input and output terminated at the optimum reflection coefficients at the 2nd and 3rd Harmonics.

MEASUREMENT METHOD

Two approaches for making this measurement are shown in figs. 1 and 2. The heart of both methods is the use of 1/4 wave resonant stubs to achieve fundamental (870MHz), 2nd and 3rd harmonic tuning at both input and output. Three of these stubs were placed at each side of the device on 50ohm, low loss microstrip lines connected to the test jig. Two of the stubs were resonant at the 2nd and 3rd harmonics and were placed at the correct distance to result in reflection coefficients at the device reference plane of a short circuit at 2nd harmonic and an open circuit at 3rd harmonic. Tuning the harmonics in this way on both input and output has previously been reported to be the optimum efficiency condition for HBT power amplifiers [5]. By adding a third resonator that resonates somewhere in the range 1000-1200MHz to both input and output at appropriate distances form the device, it was possible to set the fundamental frequency terminations to the optimum efficiency values whilst maintaining the desired harmonic impedances. It was necessary to manually optimise the length and distance from the device of the three resonators because the three interacted with each other.

By tuning the transistor this way the tuning networks are almost perfect 50ohm transmission lines well below the resonance of the longest stub (in practice < 700MHz). This means that the ANA can easily calibrate out the effect of the tuning networks in the range 50-700 MHz -

there were no large reflections that occur in this frequency range that occur when the device is tuned with either slide-screw or twin-sleeve tuners.

TEST-SET ARRANGEMENT 1

Based on this idea, figure 1 shows the device connected to the ANA through bias tees and the tuner networks. The 870MHz large signal input was connected to the device through a 3dB combiner inserted between the input bias tee and tuner network.

To prevent the 870MHz carrier from saturating and de-sensitising the ANA, two 870MHz notch filters were placed at the ANA input and output ports. Cavity resonators with >45dB rejection were required.

To terminate the fundamental power at the output, a 20dB pad was placed in the ANA port 2 path between the 870MHz notch and the collector bias tee. With this pad in place, it was still possible to calibrate the ANA for S22 and S12 measurements if the power of the ANA source was increased. (Note, however, that the internal attenuator on port 1 must be increased by the same amount that the ANA power is increased, to avoid driving the device two hard with the ANA signal during the S21 and S11 measurements).

The input match, output power and efficiency of the device at 870MHz were monitored by having two more directional couplers connected to power meters in the input and output paths. The output spectrum was also monitored with a directional coupler and spectrum analyser.

With this arrangement the device was tuned correctly for high efficiency operation at 870MHz and then the ANA was calibrated to the device reference planes over the range 50-700MHz. The s-parameters over this range could then be measured with the 870MHz drive on.

The achievable calibration range and hence the frequency range of the s-parameter measurement was limited by the bandwidth of the notch filters and the longest resonator in the trap/tuner boxes at the top end, and by the bandwidth of the bias tees at the bottom end.

To check that the ANA was not saturated by the 870MHz carrier, the device was replaced with a through connection and the 870MHz drive increased until the output power meter read the same value as the maximum power that the HBT was operated at during the measurement. With this condition the calibrated S21 trace had only a small ripple of +/- .1dB showing that the s-parameter measurements across 50-700MHz should be valid when the HBT was fully driven at 870MHz.

TEST-SET ARRANGEMENT 2

An alternative test-set-up is shown in fig.2.

This time the ANA was connected to the device through the coupled ports of 2 directional couplers that were placed between the tuner networks and the bias tees at both input and output. This allowed the 870MHz signal to be fed in directly to the device through the bias tee and tuner network and to be terminated at the output in the padded output power meter. The saturation test of the ANA could be more readily carried out with this arrangement because less power was needed from the source to achieve full output power with the through connection.

The disadvantage of this approach is that the bottom end of the measurement range is now limited by the low frequency roll-off of the directional couplers.

EXAMPLE OF MEASURED S-PARAMETERS

Figures 3 to 5 show the measured S11, S21, and S22 of a 400um (16, 25um long X 2.5um wide emitter fingers) across the range 47.2MHz-700MHz. The HBT had base ballasting of 150ohms/finger. In each case the 2nd trace shows the result when the HBT is driven at full power at 870MHz (12dBm drive, Ic=70mA, 25dBm output and 75% PAE), whilst the 1st trace shows the result when the 870MHz power is backed off (6dBm drive, Ic=40mA, 21dBm output and 50% PAE). For both of these cases the transistor is biased class B with VBB=1.2V, ICQ=2mA and VCC=6V, The 3rd and 4th traces show the small signal s-parameters for the same transistor in the standard, non-power amplifying mode at 2 currents (2mA and 70mA). Fig. 6 shows the stability factor K derived from the s-parameters.

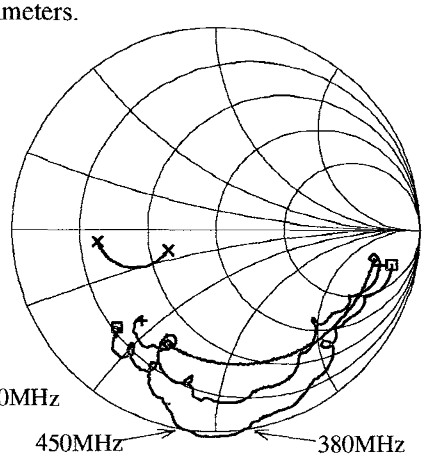

Fig. 3

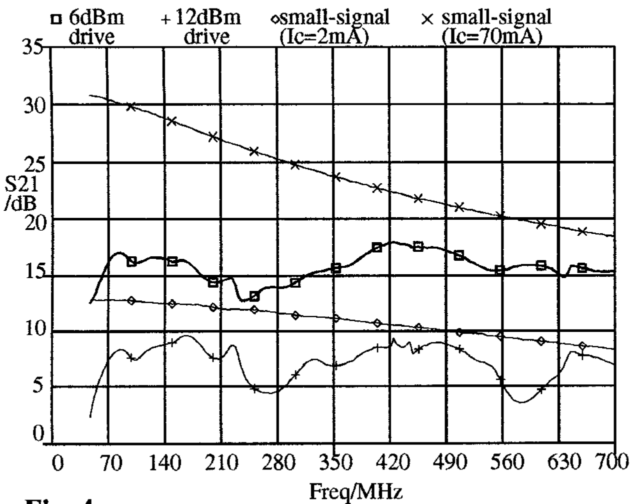

Fig. 4

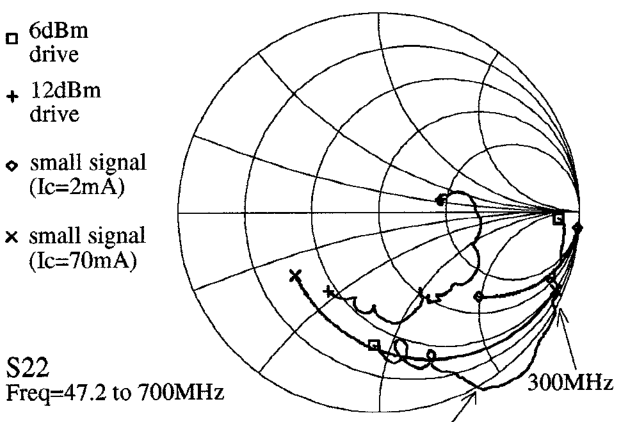

Fig. 5

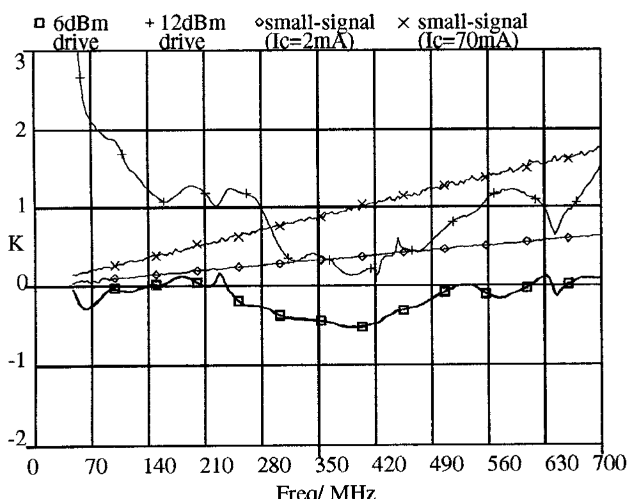

Fig. 6

DISCUSSION

Fig.4 shows the S21 curve to be suppressed below the Ic=2mA quiescent result by the 870MHz signal when the drive is 12dBm but that it is enhanced above the 2mA quiescent current case when drive is reduced to 6dBm. Figures 3 and 5 also show a marked difference between the full drive and reduced power cases for S11 and S22. In both cases, at reduced power, negative resistance is seen looking into the collector and base over the frequency range 300-450MHz (the S11 and S22 are outside the Smith Chart).

The resulting stability factor of the transistor is decreased for the 6dBm case compared to both the small signal and the 12dBm drive cases (fig 6) across the whole frequency range 50-700MHz but particularly in the range 300-450MHz..

This degradation in the stability of the HBT is consistent with the observed tendency for it to be more prone to oscillation in Class-B power amplifier circuits when the drive power is backed off, with subharmonic oscillations at f/2 and f/3 often being the oscillation mode.

CONCLUSION

1. The measurement of small-signal s-parameters over a limited frequency range whilst the transistor is driven efficiently at 870MHz has been achieved.

2. The resulting s-parameters for the example of an HBT are consistent with the observed oscillation modes of the transistor when used in power amplifiers. The s-parameters give more insight into how to stabilise power stages at frequencies below the carrier.

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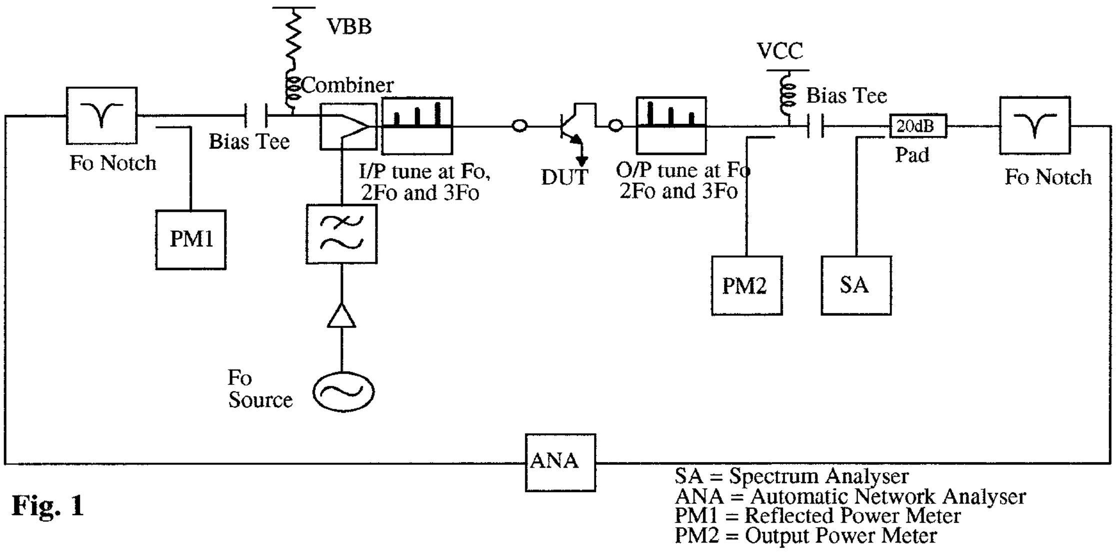

Fig. 1

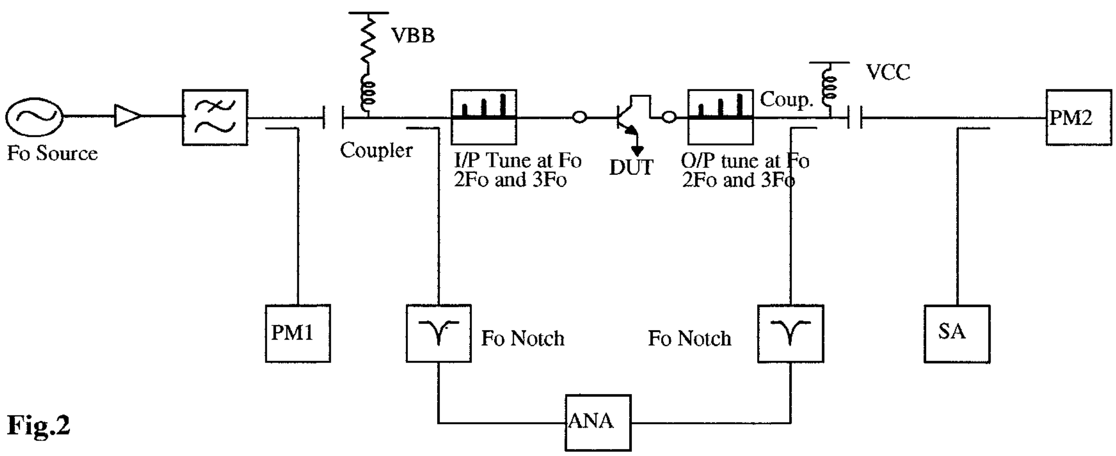

Fig.2