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AN 18 TO 26.5 GHZ WAVEGUIDE LOAD-PULL SYSTEM USING ACTIVE-LOAD TUNING

Ken Kotzebue, T.S. Tan, and Dave McQuate

Hewlett-Packard Co., Microwave Technology Division
Santa Rosa, California 95401

Abstract

An 18 to 26.5 GHz waveguide load-pull system using active-load tuning capable of measuring devices with high load reflection coefficients has been designed and constructed using standard waveguide components. The system and its application to the large-signal characterization of GaAs FETs and and amplifiers at 26 GHz will be presented.

Introduction

In 1976, Takayama proposed a novel method of making load-pull measurements which does not require the use of an output impedance tuner (1). This method, which will here be termed the "active-load" method, uses two RF signals applied to the test device: one is the usual input drive signal, and one is a signal applied to the output of the device to create the reflected wave which would otherwise come from an impedance tuner. By adjusting phase and amplitude of this second signal, in principle any load impedance may be synthesized without the need of a physical tuner.

A major advantage of this method is that the load reflection coefficient so obtained is not limited in magnitude as is the case for conventional tuners and their associated loss. With a conventional tuning scheme, for example, a tuner with 2dB of combined tuner and transmission line loss can produce a maximum reflection coefficient of only 0.63. We have, in fact, found this to be the most limiting factor in implementing load-pull systems at frequencies above 18 GHz. In this paper we describe a waveguide load-pull system covering 18 to 26.5 GHz built from "off-the-shelf" waveguide components which utilizes the active-load tuning technique to overcome this limitation. This load- pull system is integrated with a network analyzer (HP8510/11) and a controlling desktop computer to form an easily-implemented high-performance system which should be scalable with presently-available hardware up to 60 GHz.

RF Test System

A block diagram of the load-pull system is shown in Fig. 1. All transmission elements up to the device under test and its associated bias circuitry are implemented in waveguide using only "off-the-shelf" components. A photograph of the system is shown in Fig. 2. The active load is "tuned" by adjusting the attenuator and phase shifter in the output side of the system. Gain and power are measured with two dual-channel power meters, while the input reflection coefficient and the load reflection coefficient are measured with the network analyzer.

The system is configured primarily to measure FETs mounted on sapphire or alumina coplanar waveguide substrates, although it is also useful in the measurement of the large-signal performance of amplifiers. These substrates are connected to the waveguide system by means of a custom-designed fixture which holds the substrate and provides transitions to APC-3.5 coaxial connectors. This test fixture is then connected to the waveguides by means of standard coaxial-to-waveguide transitions. Biasing of the FETs has been accomplished either with commerically-available APC-3.5 26.5 GHz bias tees, or in some instances with a custom-fabricated network built into a coaxial-to-waveguide transition. This later biasing approach is sometimes necessary to avoid test device oscill-

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ations caused by high reflections from the coaxial-to-waveguide transitions which occur at frequencies below waveguide cutoff. To solve this problem, a coaxial-to-waveguide transition was modified to become a simple frequency diplexer wherein an added coaxial low-pass filter is used to both introduce bias and also resistively terminate the original coaxial port of the transition at frequencies below waveguide cutoff.

Calibration

The calibration of a load-pull system is similar to the calibration of a small-signal S-parameter test system. For device measurements the calibration standards used with this system are an open circuit, short circuit, a through standard, and low-reflection resistive termination, all fabricated on sapphire coplanar waveguide substrates. This allows for calibration at the actual reference plane of the device under test without the need for de-imbedding routines. All of these standards are used to calibrate the network analyzer. The short circuits and through are used to set appropriate offsets into the dual-channel power meters so that incident, reflected, and net power can be read directly for both the input and output ports. (In principle, only one power meter is required in a load-pull system using a network analyzer, but in this application four power meters (two dual-channel units) have been used to provide redundant information useful for evaluating system accuracy.) The absolute power level is measured at the point where the test fixture is connected to the bias network or coaxial-to-waveguide transition, and is offset by one-half the total test fixture insertion loss so that input power is referenced to the actual power at the input reference plane of the device. For amplifier measurements the calibration is simpler in that conventional APC-3.5 calibration standards can be used.

Control and Data Acquisition

Since the active-load turning is accomplished with a standard manually-controled phase shifter and attenuator, it was not feasible to fully automate the test system. Nevertheless, since all of the test instruments have either IEEE-488 or HP-IL bus capability, it was possible to use a desktop computer for control and data acquisition. The computer is used to control the source frequency and power level, the network analyzer response, receive and store data from the voltmeters, current meters, and power meters, and to process and display the data and results. Once the output load has been set, the computer controls the measurement process and prints out in tabular form input power, output power, power gain, added power, drain and gate voltages and current, and power-added efficiency; all over the desired range of input power. A further output is a graphical display of power gain as a function of output power. When load-pull power contours are desired, the incident input power level is held constant and the active load is changed manually by varying the phase shifter and attenuator. An example of a run of data on this system at 26 GHz is shown in Figs. 3, 4, & 5 for the case of a 0.3μGaAs MESFET with a gate width of 350μ. An example of a measurement made on a single-stage test amplifier with this system is shown in Fig. 6. A corresponding small-signal sweep made on a separate network analyzer system is shown in Fig. 7; the agreement in gain as measured on the two systems is within 0.3dB.

Conclusion

A waveguide load-pull system using active-load tuning has been implemented in the 18 to 26.5 GHz frequency band. Such an approach to load-pull systems is felt to be necessary above 18 GHz where system losses cause low performance with more conventional schemes. This system uses standard waveguide hardware and should be scalable to 60 GHz when used in conjunction with network analyzer frequency enhancements described in the literature (2).

Acknowledgements

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References

(1) Y. Takayama, "A New Load-Pull Method For Microwave Power Transistors,", Dig. Tech. Papers, IEEE G-MTT Int. Microwave Symp., pp. 218-220, 1976.

(2) Hewlett-Packard Product Note 8510-1A.

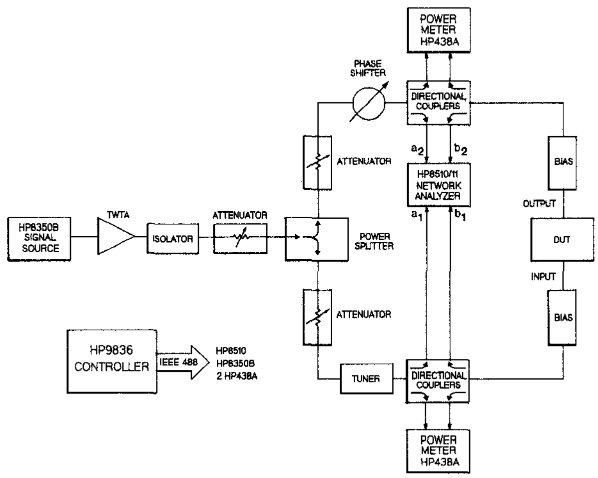


Fig. 1 Block diagram of 18-26.5 GHz load-pull system with active-load tuning.

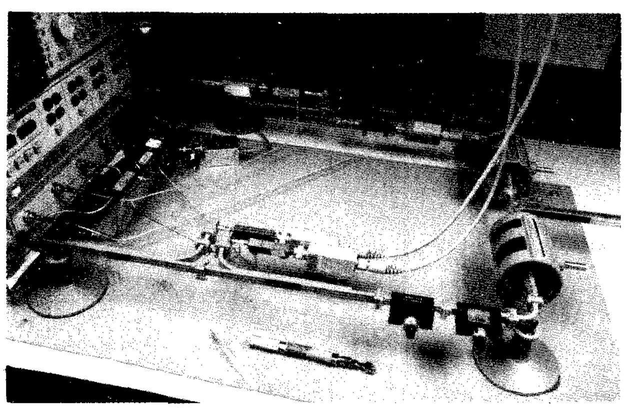
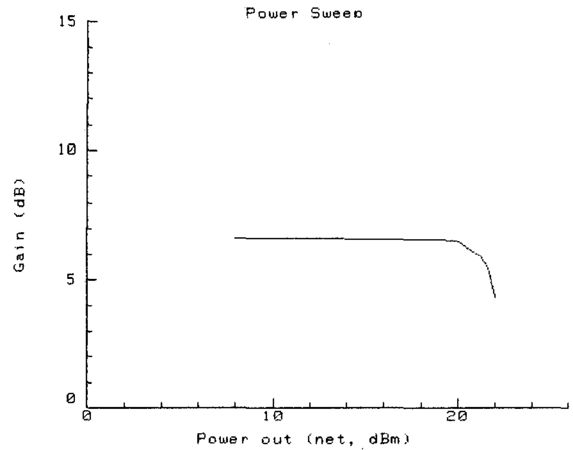


Fig. 2 Photograph of load-pull system.



Bias: -.398
Vd = 5.03; Ids(quiescent) = 65 mA
Frequency = 26 GHz
MBE 624 #26 350u
Tuned @ 20.5dBm out. Load=.57/125. Biased @ 75% Ids, tuned for max. power out.
11:18:48 27 Aug 1986

#	Pin_net	Pout_net	Gain	Padd(mW)	Ids(mA)	Igs(mA)	Vgs	P added eff
1	1.36	7.98	6.62	4.9	60	0.00	-.40	1.6
2	3.50	10.15	6.65	8.1	60	0.00	-.40	2.7
3	5.91	12.53	6.62	14.0	61	0.00	-.40	4.6
4	8.75	15.35	6.60	26.8	62	0.00	-.40	8.6
5	10.88	17.48	6.60	43.7	64	0.00	-.40	13.6
6	12.24	18.84	6.60	59.8	65	0.00	-.40	18.3
7	13.37	19.93	6.56	76.7	65	.03	-.41	23.5
8	15.31	21.27	5.96	100.0	59	.38	-.59	33.7
9	16.08	21.61	5.53	104.3	55	.64	-.72	37.7
10	17.64	22.00	4.36	100.4	48	1.37	-1.10	41.6

ref. Pin= 3.50 One dB compressed power= 21.52dBm; gain= 5.65dB
P_out at maximum added power= 21.6 dBm; gain= 5.5 dB

Fig. 3 Example of GaAs FET (0.3μx 350μ) gain/power data at 26 GHz.

Bias: -.398
Vd = 5.03; Ids(quiescent) = 65 mA
Frequency = 26 GHz
MBE 624 #26 350u
Tuned @ 20.5dBm out. Load=.57/125. Biased @ 75% Ids, tuned for max. power out.
11:18:48 27 Aug 1986

#	mag S11	phase	mag S21	phase	mag S22	phase
1	.841	-178.8	1.431	11.3	.569	125.4
2	.842	-178.8	1.434	11.4	.575	125.3
3	.843	-179.1	1.430	11.3	.571	125.3
4	.841	-179.3	1.431	11.2	.574	125.6
5	.841	-179.3	1.430	11.3	.574	125.4
6	.840	-179.5	1.429	11.3	.574	125.4
7	.843	-179.5	1.426	11.4	.576	125.4
8	.836	-178.8	1.344	11.2	.574	125.2
9	.832	-177.8	1.283	10.9	.569	125.0
10	.825	-174.7	1.143	9.6	.571	125.6

Fig. 4 Example of GaAs FET (0.3μx 350μ) network analyzer large-signal output at 26 GHz.

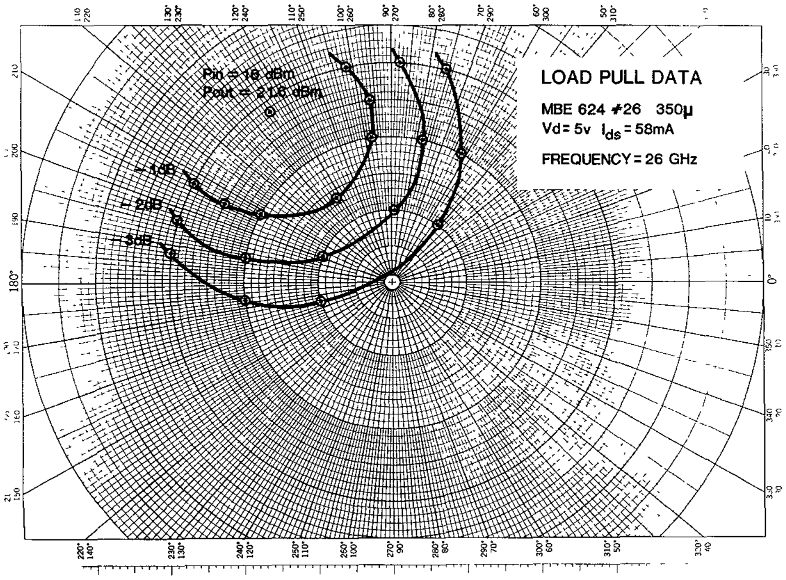
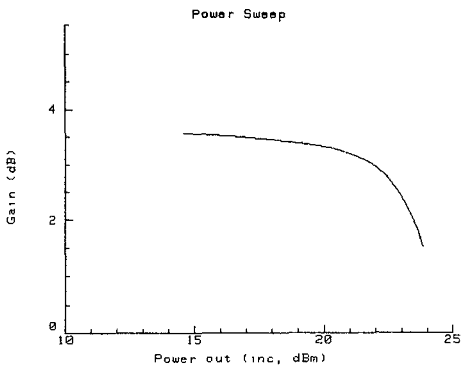


Fig. 5 Example of GaAs FET (0.3μx 350μ) load-pull data at 26 GHz.



Bias· -.2
Vd = 6.06, Ids(quiescent) = 190 mA
Frequency = 26 GHz
8 to 26GHz Amp. MBE 767A #44R
Amp. K-9
21 May 1986

Pin_inc	Pout_inc	Gain	Ids(mA)	Igs(mA)	Vgs
11.01	14.57	3.56	192	0.00	-.21
11.81	15 36	3.55	192	0.00	- 21
11.96	15.50	3.54	192	0.00	-.21
12.00	15 53	3.53	192	0.00	- 21
12.82	16.34	3.52	192	0.00	- 21
13.65	17.14	3 49	193	- 01	-.21
14.50	17.96	3.46	193	0.00	-.21
15.36	18.77	3.41	193	0.00	-.21
16.22	19.57	3.35	194	0.00	-.21
17 08	20.36	3.28	194	0 00	-.21
17.95	21.12	3 17	194	0.00	-.21
18.80	21 82	3.02	192	.03	- 23
19.63	22.42	2.79	187	12	- 27
20.43	22.92	2.49	179	.25	- 34
21.16	23.31	2.15	170	.43	- 43
21.81	23.63	1 82	160	.63	-.53
22.31	23.83	1.52	152	80	-.62
22.30	23.83	1.53	152	.80	- 62

One dB compressed power= 22.80dBm, gain= 2.56dB

Fig. 6 Example of gain/power data for single-stage GaAs FET (0.3μx 750μ) test amplifier at 26 GHz.

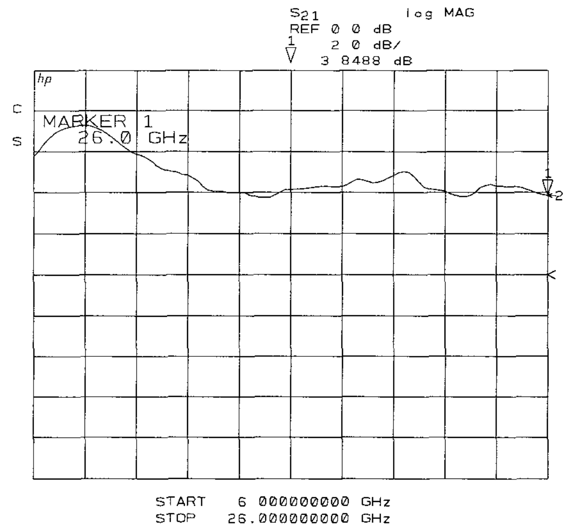


Fig. 7 Small-signal-gain frequency response of single-stage GaAs FET (0.3μx 750μ) test amplifier.