7R/IN/33

A 90 GHz Amplifier Assembled Using a Bump-bonded InP-based HEMT

Authors:
Paul R. Pinsukanjana, Lorene A. Samoska, Todd C. Gaier, R. Peter Smith, Alexander Ksendzov, Michael J. Fitzsimmons, Suzanne C. Martin, Jet Propulsion Laboratory, Pasadena, CA 91109

Richard Lai, TRW Inc., Redondo Beach CA 90278

We report on the performance of a novel W-band amplifier fabricated utilizing very compact bump bonds. We bump-bonded a high-speed, low-noise InP high electron mobility transistor (HEMT)[1] onto a separately fabricated passive circuit having a GaAs substrate. The compact bumps and small chip size were used for efficient coupling and maximum circuit design flexibility. This new *quasi*-monolithic millimeter-wave integrated circuit (Q-MMIC) amplifier exhibits a peak gain of 5.8 dB at ~90 GHz and a 3 dB bandwidth of greater than 25%. To our knowledge, this is the highest frequency amplifier assembled using bump-bonded technology. Our bump-bonding technique is a useful alternative to the high cost of monolithic millimeter-wave integrated circuits (MMIC's). Effects of the bumps on the circuit appear to be minimal.

We used the simple matching circuit shown in Fig. 1 for demonstrating the technology – future circuits would have all of the elements (resistors, via holes, bias lines, etc.) included in conventional MMIC's. The equivalent circuit of the amplifier is shown in Fig. 2. Our design in different from other investigators' efforts [2-6] in that the bumps are only 8 microns thick by 15 microns wide. The bump sizes were sufficiently small that the devices, originally designed for W-band hybrid circuits, could be bonded without alteration.

Figure 3 shows the measured and simulated magnitude of S-parameters from 85-120 GHz, of the InP HEMT bump-bonded to the low noise amplifier (LNA) passive circuit of Figure 1. The maximum gain is 5.8 dB at ~90 GHz, and gain extends to 117 GHz. Measurement of a single device (without matching networks) showss ~1 dB of gain at 90 GHz. The measured gain of the amplifier agrees well with the design in the center of the measurement band, and the agreement falls off at the band edges. Since no accommodation for the bump-bonding parasitics was made in the design, the result implies that the parasitic elements associated with the bonding itself do not dominate the performance of the LNA circuit. It should be noted that this amplifier was designed for good noise performance, which is why the input and output return losses are poorer than one would expect for an amplifier simply matched for gain. However, noise performance has not been measured at this time. While the agreement between modeled vs. experimental data is not exact, the data prove that bump-bonded technology can be used for amplifiers at frequencies at least as high as 100 GHz.

JPL is pursuing this technology as a way to economically and quickly incorporate the best available HEMTs into a circuit with all of the reliability and circuit design flexibility offered by MMIC technology. We are currently using the technology to fabricate 4-stage, wide-band, W-band LNA's. We have also performed pull and shear tests which show that the bump bonds are sufficiently robust for any anticipated application.

[1] M. Wojtowicz, R. Lai, D. C. Streit, G. I. Ng, T. R. Block, K. L. Tan, P. H. Liu, A. K. Freudenthal, and R. M. Dia, "0.10 μm graded InGaAs channel InP HEMT with 305 GHz f_T and 340 GHz f_{max}," *IEEE Electron Device Lett.*, vol. 15, no. 11, pg. 477, 1994.
[2] T. Hirose, K. Makiyama, K. Ono, T. Miyata Shimura, S. Aoki, Y. Ohashi, S. Yokokawa, and Y. Watanabe, "A Flip-Chip MMIC Design with Coplanar Waveguide Transmission Line in the W-Band," in *IEEE Trans. on Microwave Theory Tech.*, vol. 46, pg. 2276, 1998.
[3] M. Ito, K. Maruhashi, H. Kusamitsu, Y. Morishita, and K. Ohata, "Analysis of Flip-chip MMIC Structure for 60-and 76-GHz Low Noise Amplifiers," in *Proc. Asia-Pacific Microwave Conf.*, 1998, p. 299.
[4] Wolfgang Menzel, "Interconnect and Packaging Techniques for Complex Millimeter Wave Front-Ends,"in *Proc. Asia-Pacific Microwave Conf.*, 1998, p. 283.
[5] R. S. Virk, S. A. Maas, M. G. Case, M. Matloubian, P. Lawyer, H. C. Sun, C. Ngo, and D. B. Rensch, "A Low-Cost W-Band MIC Mixer Using Flip-Chip Technology," *IEEE Microwave and Guided Wave Lett.*, vol. 7, no. 9, pg. 294, 1997.
[6] Y. Arai, M. Sato, H. T. Yamada, T. Hamada, K. Nagai, and H. I. Fujishiro, "60-GHz Flip-Chip Assembled MIC Design Considering Chip-Substrate Effect," *IEEE Trans. on Microwave Theory Tech.*, vol. 45, pg. 2261, 1997.

Contact information: r.peter.smith@jpl.nasa.gov, (818) 354-4424(ph), (818) 393-4540 (fax), M/S 302/306, Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109

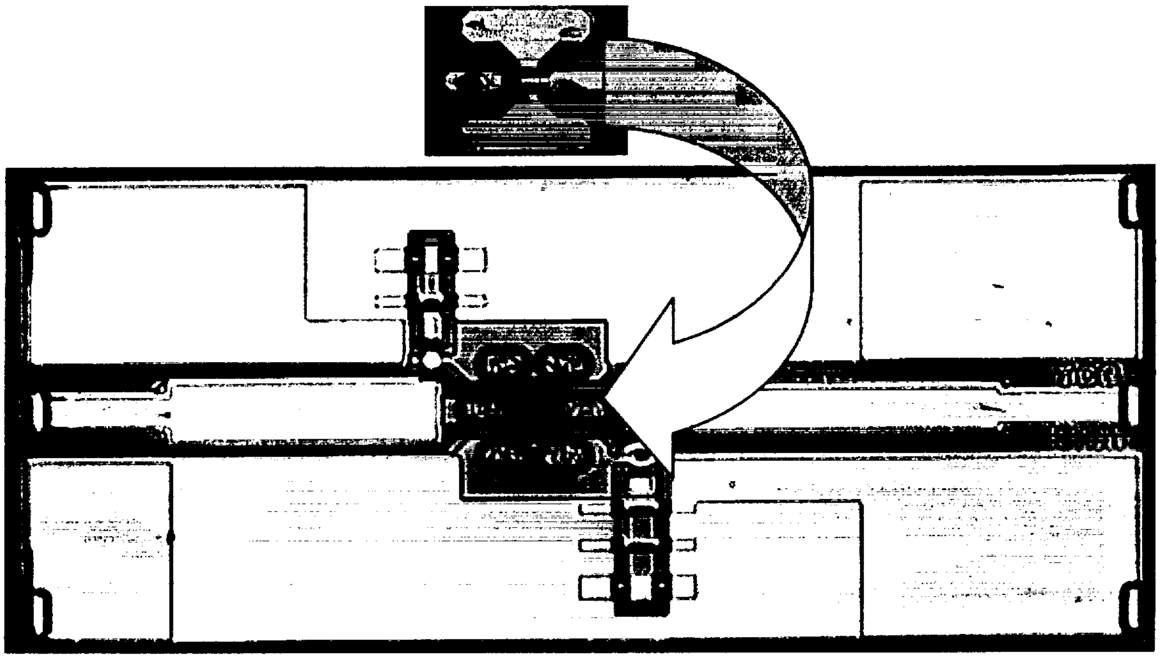

Figure 1. The passive W-band amplifier circuit and InP-based HEMT with 0.1μm x 40 μm gates. The electroplated Au/Sn bumps in the center are used for bump bonding. Input and output matching capacitors are connected to the cpw transmission lines through series air bridges.

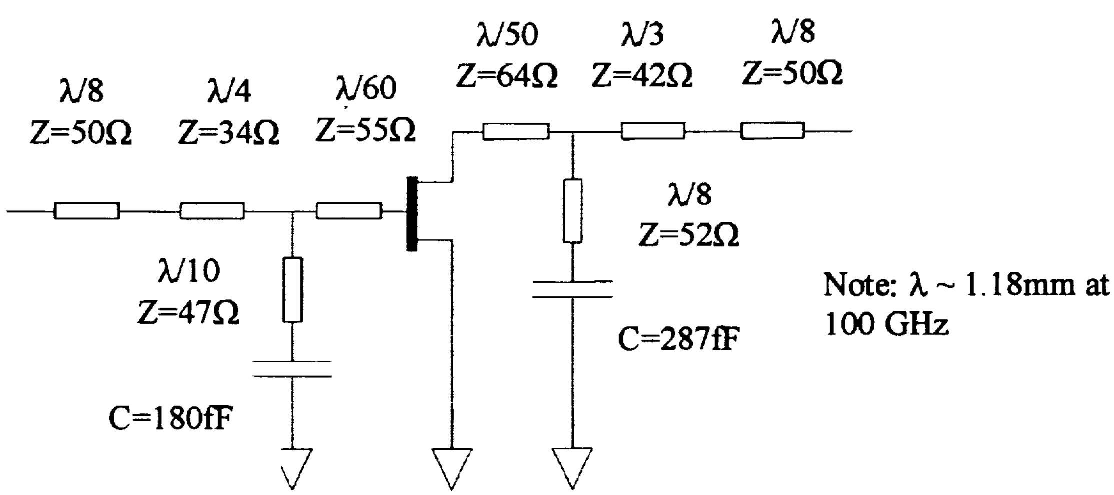

Figure 2. Equivalent circuit of the amplifier.

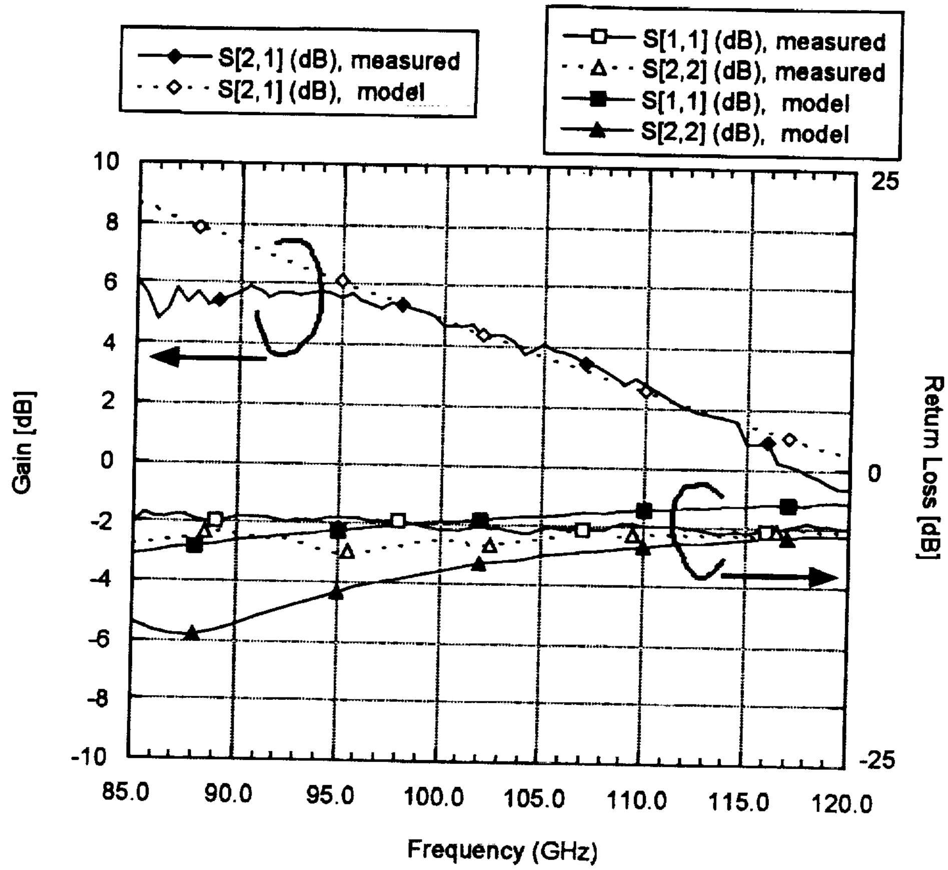

Figure 3. Magnitude of the measured and modeled S-parameters for the W-band amplifier. The bias conditions were $V_{gs} = 0.1$ V, $V_{ds} = 1$ V, and $I_{ds} = 11$ mA. Both the measured and modeled gain and reflection coefficients are not state-of-the-art because the circuit was designed with bandwidth and low-noise performance as objectives. We have not yet had the opportunity to measure the noise figure of the circuit.