36.0 - 40.0 GHz HEMT LOW NOISE AMPLIFIER

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Abstract

This paper describes the design and development of a multistage low noise High Electron Mobility Transistor (HEMT) amplifier that exhibits state-of-the-art performance over the frequency range of 36-40 GHz. The amplifier utilizes a series of three single ended stages that are each designed around TRW'S HEMT device. Typical performance to date has been 15-17 dB gain with an associated noise figure of 4.0 to 4.6 dB.

Introduction

Until 1982 the conventional GaAs MESFET technology was rapidly approaching the limits of photolithography and fabrication techniques. Performance parameters at upper Ka-band (40 GHz) were inadequate for many receiver applications where preamplifier stages required low noise figures and high gains. With the advent of (HEMT) technology, there now exists an active device that has the potential to replace the MESFET as the device that is used in the low noise amplifiers.

High Electron Mobility Transistors (HEMT) have been fabricated which exhibit lower noise figure and higher gain at millimeter-wave frequencies than previously reported (1). Although similar in construction to the devices reported earlier, considerable progress has been made in optimizing both the epitaxial structure and the parasitic elements of the devices used in this work. Quarter-micron gate length transistors were fabricated by direct-write electron beam lithography on epitaxial layers grown by molecular beam epitaxy. The gain and noise performance achieved with these improved HEMT devices rivals the best measured for "state-of-the-art" GaAs MESFET's having the same length.

DEVICE FABRICATION

For device fabrication, single heterojunctions were grown by molecular beam epitaxy with a graded aluminum composition contact as shown in the device cross-section of Figure 1. By grading the aluminum composition over several hundred angstroms, it is possible to eliminate the barrier to current flow in the top contact layer. This modification of the epitaxial structure reduces contact resistance and increases the sheet electron concentration. The saturated drain-source current of the resulting devices is double that previously obtained with an abrupt n+ GaAs contact. Due to the greater current handling capability, these devices exhibit higher extrinsic transconductance, higher gain, and greater power output than conventional GaAs FET'S. Reduction of the source-gate resistance has lowered the noise figure. Direct-write electron beam lighography was utilized to define quarter-micron gate lengths. Reduction of the gate-source capacitance is also responsible for lowering noise figure and increasing gain.

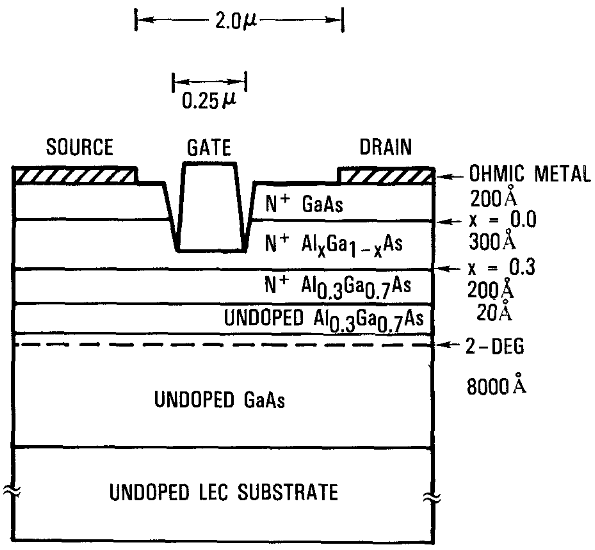

Figure 1. Cross section of HEMT device.

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To provide guidance in optimizing device performance, an analytical model has been developed to relate the dc and small-signal characteristics of the device to the physical structure. The lowest and first energy subbands of the quantum well have been incorporated in the model to improve its accuracy in describing measured device properties as a function of bias. Excellent agreement has been achieved between calculated and measured noise figure as a function of frequency using the Fukui equation [2]. Figure 2 compares the calculated noise figure and gain of a quarter-micron HEMT device made using the current technology with the measured performance of our experimental devices is close to the theoretical prediction.

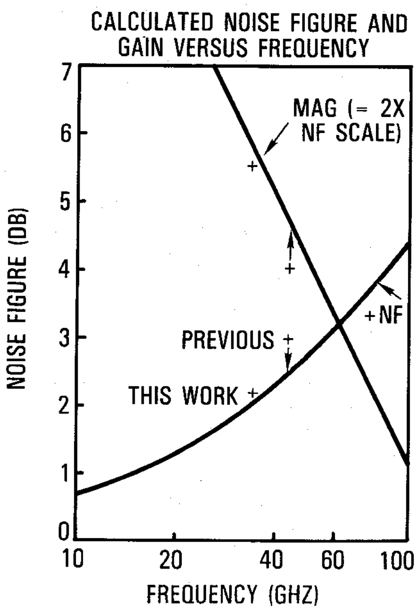

Figure II. Noise figure and gain vs. frequency.

CIRCUIT DESIGN & CONSTRUCTION

The amplifier was constructed utilizing microstrip techniques, but due to the high frequency of operation a direct waveguide to microstrip transition was required to facilitate the assembly and testing of the individual amplifier states. As shown in Figure III the transitions were of the finline configuration [3] that utilizes a titanium tungsten, gold metallization,

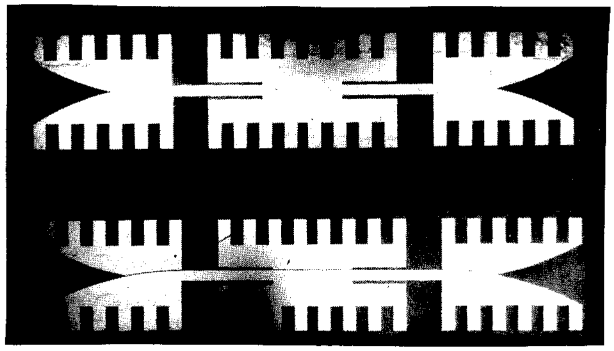

Figure III. Waveguide to microstrip transition.

with the pattern photoetched onto 0.010" thick highly polished quartz substrate. This type of transition was chosen over the more common E-field probe which utilizes an adjustable backshort for tuning because of its greater bandwidth, lower insertion losses and an excellent VSWR. This transition requires no mechanical connection to the amplifier circuit as would a ridged waveguide transition, and allows construction of planar type amplifiers on carriers that are easily tuned and can be assembled into multistage amplifier chains. For a single stage amplifier there is no need for D.C. blocking capacitors, since there is no direct contact of the circiut metallization with the housing. The transition represents a combination of computer design and optimization. It is easily reproducible by photo-lithographic techniques. By using a (CAD) Computer Aided Design system, the turn-around-time for successive iterations and modifications was greatly reduced. Insertion loss and return loss for the transitions are shown in Figure IV. All

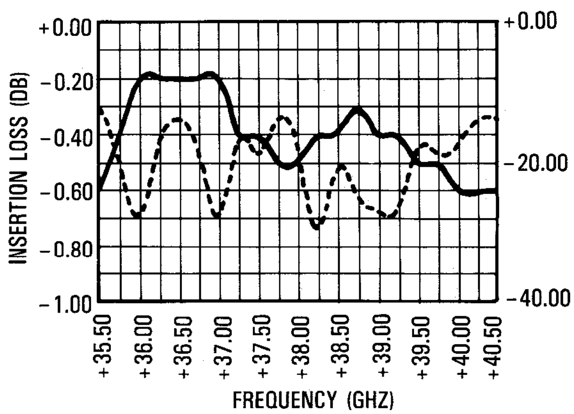

Figure IV. Waveguide to microstrip transition insertion loss and return loss.

data is for two transitions placed back-to-back. The transitions are broadband and exhibit excellent performance over the band of interest.

A single stage amplifier was constructed using distributed matching elements as shown in Figure V.

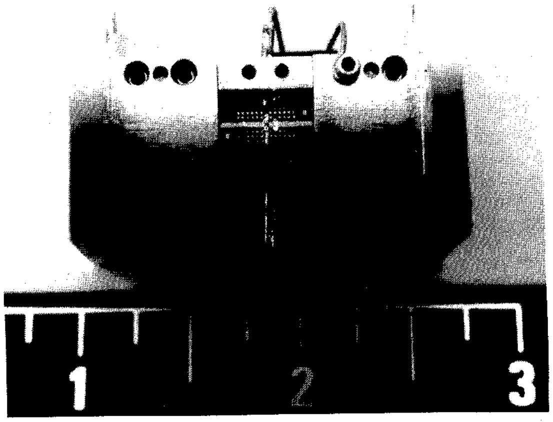

Figure V. Single stage amplifier.

The bias networks were computer optimized to insure out-of-band stability. The circuitry was photo-etched onto 0.010" thick quartz substrate using the same processes and metallization as the transitions. The amplifier housing was designed to eliminate any possible moding problems and to minimize radiation losses. Invar was chosen as the material for the carrier because its coefficient of expansion matches that of the quartz substrate.

The amplifier's noise figure was optimized by a selective mismatch of the input circuit consistent with adequate gain. The output was then tuned to compensate for the gain ripple and gain rolloff introduced by the noise tuning. Single stage amplifier performance is shown in Figures VI and VII. The 1 dB compression point at 38 GHz was +6 dBm, and the third order intercept point was typically +14 dBm.

A three stage amplifier was designed as a series of single ended cascaded stages as shown in Figure VIII. In order to optimize the amplifier's noise figure and gain an input isolator was not used. This same rationale led to the selection of a single-ended amplifier configuration so that quadrature hybrid losses associated with balanced stages could be avoided. Each stage was constructed and tuned seperately, and then mounted onto an aluminum supercarrier for installation into a

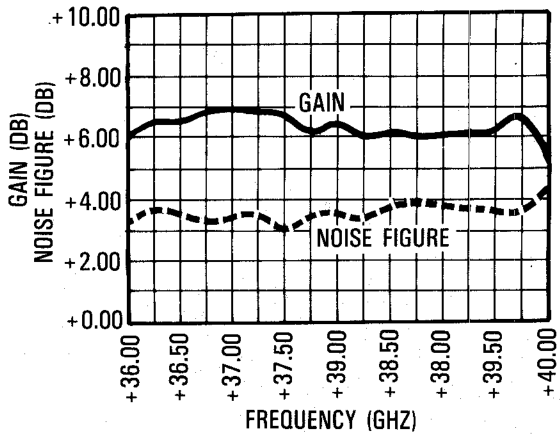

Figure VI. Noise figure and gain of single stage amplifier.

hermetic receiver housing. Only moderate retuning of the first and second stage input circuitry was required after the pre-tuned stages were introduced into the multistage amplifier assembly. The output circuit of the third stage was retuned slightly to produce a flatter passband gain ripple.

Gain and noise figure of the multi-stage amplifier is shown in Figure IX. The gain was optimized and measured utilizing the standard hot/cold Y-factor method.

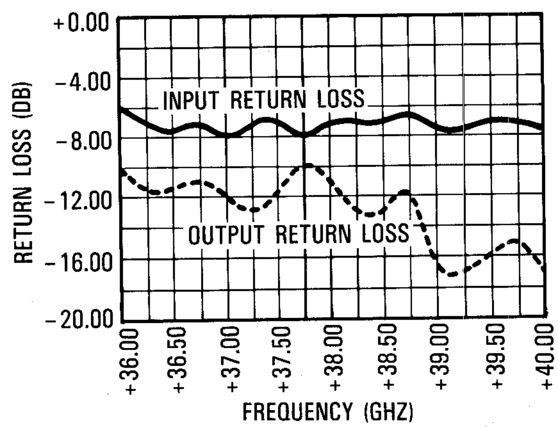

Figure VII. Input and output return losses for single stage amplifier.

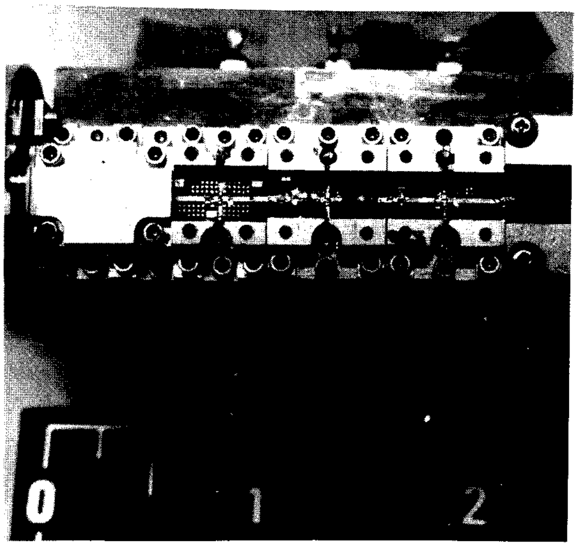

Figure VIII. Three stage amplifier.

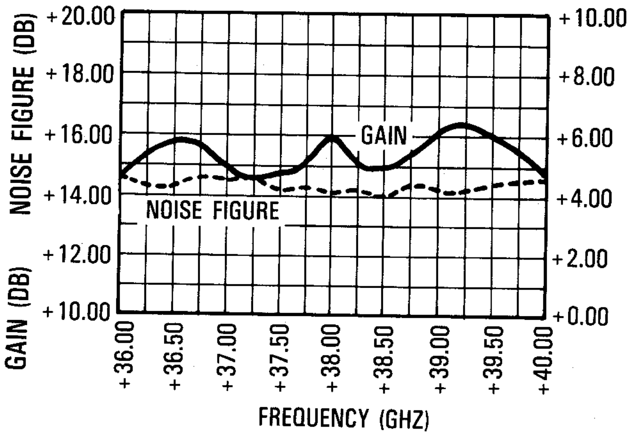

Figure IX. Noise figure and gain of three stage amplifier.

CONCLUSIONS

HEMT technology now makes possible receiver performance comparable to that currently achievable at Ku and K band frequencies. Combining low noise HEMT preamplifiers with planar construction techniques makes it possible to build high frequency high performance receivers that are low in cost, easily reproducible, light in weight, small size and with low power requirements. Utilizing HEMT devices, the authors have constructed the first reported single and three stage amplifiers, at 36-40 GHz that surpasses that of GaAs FET technology.

Further refinements of HEMT technology directed at reducing device parasitcs will eventually allow even better sensitivity and higher gains than described in this paper. Reduction of gate metal resistance and source-gate resistance will result in HEMT device and amplifier noise figures that are lower than those reported here. In addition, higher frequencies of operation will be achieved with HEMT devices than GaAs MESFET'S because of its superior electron mobility and saturation velocity.

ACKNOWLEDGMENT

This work was performed at TRW in the Communications System Development Department under an Independent research and development program. The authors would like to thank Mr. Edward A. Freitas for the mechanical design of the carriers, housings and layouts.

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