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Space Power Amplification With Active Linearly Tapered Slot Antenna Array

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SPACE POWER AMPLIFICATION WITH ACTIVE LINEARLY TAPERED SLOT ANTENNA ARRAY

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Abstract

A space power amplifier composed of active linearly tapered slot antennas (LTSAs) has been demonstrated and shown to have a gain of 30 dB at 20 GHz. In each of the antenna elements, a GaAs monolithic microwave integrated cir-cuit (MMIC) three-stage power amplifier is integrated with two LTSAs. The LTSA and the MMIC power amplifier have a gain of 11 dB and power added efficiency of 14 percent respectively. The design is suitable for constructing a large array using monolithic integration techniques.

Introduction

The power output as well as the dynamic range of microwave solid state devices decreases as the frequency of operation increases. Hence to obtain high power at fundamental frequencies of several tens of GHz, the output from all the devices have to be combined using either conventional power combiners or quasi-optical power combiners.[1] In the case of conventional power combiners, the combining is done with Wilkinson, radial line, and hybrid coupled networks. In the case of quasi-optical combiners, oscillators constructed with IMPATT diodes,[2] Gunn diodes,[3] MESFETs,[4] or HEMTs[5] are integrated with microstrip patch antennas or linearly tapered slot antennas (LTSAs)[6] to form an active antenna array which combines power radiatively in free space. The advantages of quasi-optical power combiners over conventional power combiners are higher combining efficiency because of lower conductor losses and larger dimensional tolerances with the absence of resonance modes. In addition both antennas and devices can be integrated on a single semiconductor wafer thus simplifying the array construction. The disadvantage of oscillator based quasi-optical combiners is that the individual oscillators have to be phase locked to a reference source or the active array has to be placed in a Fabry-Perot resonator to produce coherent radiation.

Another way to obtain high power is to construct a spatial amplifier. One such scheme is the grid amplifier.[7] Each unit cell of the grid amplifier consists of a pair of packaged GaAs MESFETs with the sources connected together to form a differential amplifier and with the gate and drain terminals extending radially to form a pair of orthogonal strip antennas. Radiation to and from a planar array of identical unit cells is quasi-optically coupled by a vertically or a horizontally polarized beam respectively.

This paper presents for the first time a spatial amplifier with GaAs monolithic microwave integrated circuit (MMIC) multi-stage power amplifiers. In this approach an array of active antenna modules constructed from nonplanar LTSAs[8] and GaAs MMIC amplifiers receives signals at lower power, and after amplification re-radiates signals into free space. The two advantages of the spatial amplifier over the spatial oscillator are that only a single stable lower power source is required (thus greatly simplifying the combiner construction) and that the amplifiers can be individually optimized. Figure 1 schematically illustrates a possible arrangement for space power amplification.

Active Antenna Module Characteristics

The experimental three-element array module is showns chematically in Figure 2. The array elements are constructed by integrating a GaAs MMIC multi-stage power amplifier between two nonplanar LTSAs.

Linearly Tapered Slot Antenna

The feed system of the nonplanar LTSA consists of a conventional microstrip with the ground plane tapered to form a balanced microstrip. The strip conductors of the balanced microstrip are gradually flared with respect to the antenna axis to form the nonplanar LTSA. The design of the non-planar LTSA and its characteristics are reported in Ref. 8. The antenna is fabricated on a 0.02 inch thick RT-5880 Duroid substrate. The measured gain of the LTSA is about 11 dB at the center frequency of 20 GHz. The LTSA has a return loss S_{11} of 10 dB (2:1 VSWR) over a bandwidth extending from 10 to 30 GHz.

GaAs MMIC Multi-Stage Power Amplifier

The GaAs MMIC three-stage power amplifier was designed and fabricated by Texas Instruments for NASA Lewis Research Center.[9] A photograph of the amplifier chip is shown in Figure 3. The amplifier is constructed on a GaAs substrate with an active layer doping level of 2.5×10^{17} cm^{-3}. The gate widths of the three stages are 1.2, 2.4, and 6.0 mm, respectively, and the gate length is 0.5 μm in all the stages. The chip size is about 4.0 by 3.0 by 0.1 mm. The bias network is incorporated on the chip. The drain voltage V_d and current I_d is 6.3 V and 1.9 A, respectively. The gate voltage

V_g is -0.6 V. The measured gain (S_{21}) on a HP 8510B ANA with a 40 dB coaxial attenuator on the drain side of a typical amplifier is shown in Figure 4. The gain is greater than 10 dB over the frequency range of 18 to 21 GHz. The saturated output power measured on a Pacific Instruments scalar network analyzer at 20 GHz is about 1.8 W with a gain of 10 dB and power added efficiency of 14 percent.[9]

Experimental Results and Discussions

A simple measurement procedure has been developed to estimate the gain of the space amplifier. This procedure involves the LTSAs at the input terminals are space fed from a single horn antenna while those at the output terminals radi-ate into free space. The free space radiation is picked up by a second horn antenna which is placed at a far field distance from the array. The ratio of the measured received power with and without bias to the MMIC amplifiers provides an estimate of the gain of the space amplifier. In the setup, the two horn antennas are orthogonally polarized but the LTSAs are oriented to have the same polarization as their respective horn antennas, thus good isolation between the transmitting and the receiving horn antennas is established. Also, for comparison purposes, a single LTSA was tested as a receive antenna. The H-plane pattern is shown in Figure 5 which exhibits a power gain of 6.7 dB with the MMIC amplifier turned ON.

Three-Element Array Module

In this experiment, the LTSAs at the amplifier input and output are oriented with the H and E vectors of the receiving horn, respectively as shown in Figure 6(a). This arrange-ment allows the horn to excite the three LTSAs with equal amplitude. The measured radiation pattern is shown in Figure 7(a) with the amplifiers turned ON and OFF, respectively. The gain increases by as much as 30 dB when the amplifiers are turned ON which is in good agreement withthe measured gain of the amplifiers.

A second experiment, as shown in Figure 6(b), is carried out with the LTSAs at the input and output oriented with the H and E vectors of the receiving horn, respectively. The measured radiation pattern is shown in Figure 7(b). In this arrangement the gain increases by 25 dB when the amplifiers are turned ON. The gain is lower in this case because the LTSAs on either side of the center element are excited with a lower amplitude due to the amplitude taper of the electric field distribution of the transmitting horn. The experimental three element LTSA MMIC array module is shown in Figure 8.

Conclusions

A space power amplifier composed of active LTSA antennas has been demonstrated and shown to have a gain of 30 dB at 20 GHz. In each of the antenna elements, a MMIC three-stage power amplifier is integrated with two LTSAs. The GaAs MMIC power amplifier and the LTSA have a power added efficiency of 14 percent and a gain of 11 dB, respectively. The design is suitable for constructing a large array using monolithic integration techniques.

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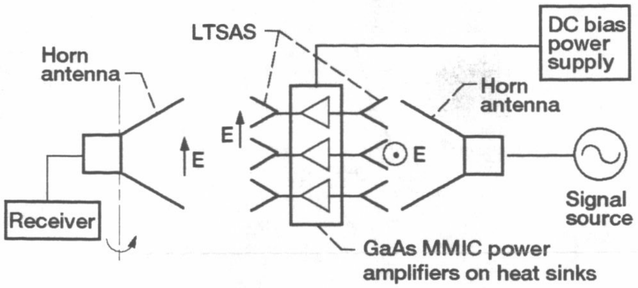

Figure 1.—Schematic illustrating a possible arrangement for space amplification.

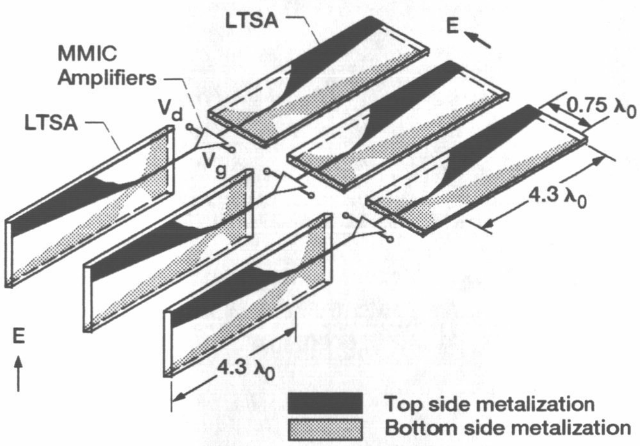

Figure 2.—Schematic illustrating the three-element array module. (λ_0: free space wavelength.)

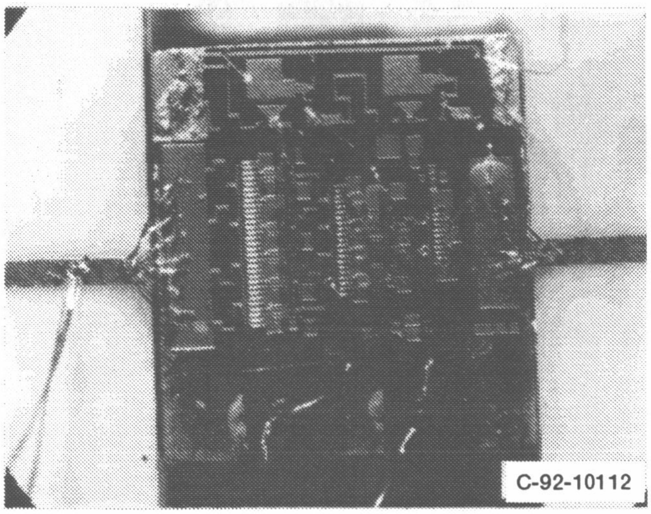

Figure 3.—GaAs MMIC three-stage power amplifier.

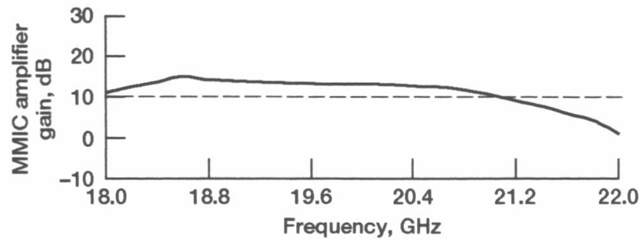

Figure 4.—Typical measured gain of MMIC amplifier.

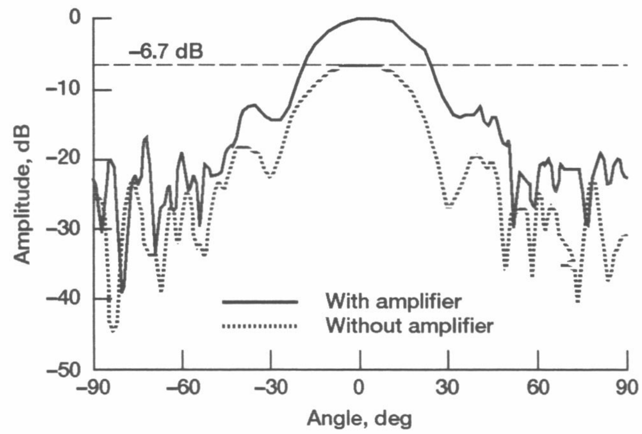

Figure 5.—The measured H-plane radiation pattern of a single LTSA with and without the amplifier.

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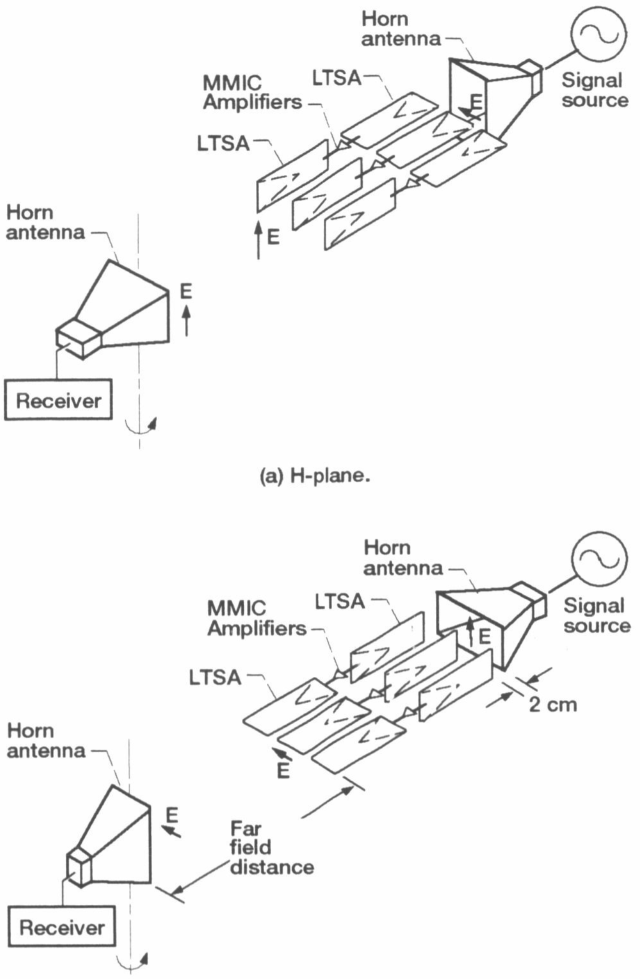

Figure 6.—LTSA orientation in the three-element array module for gain measurement.

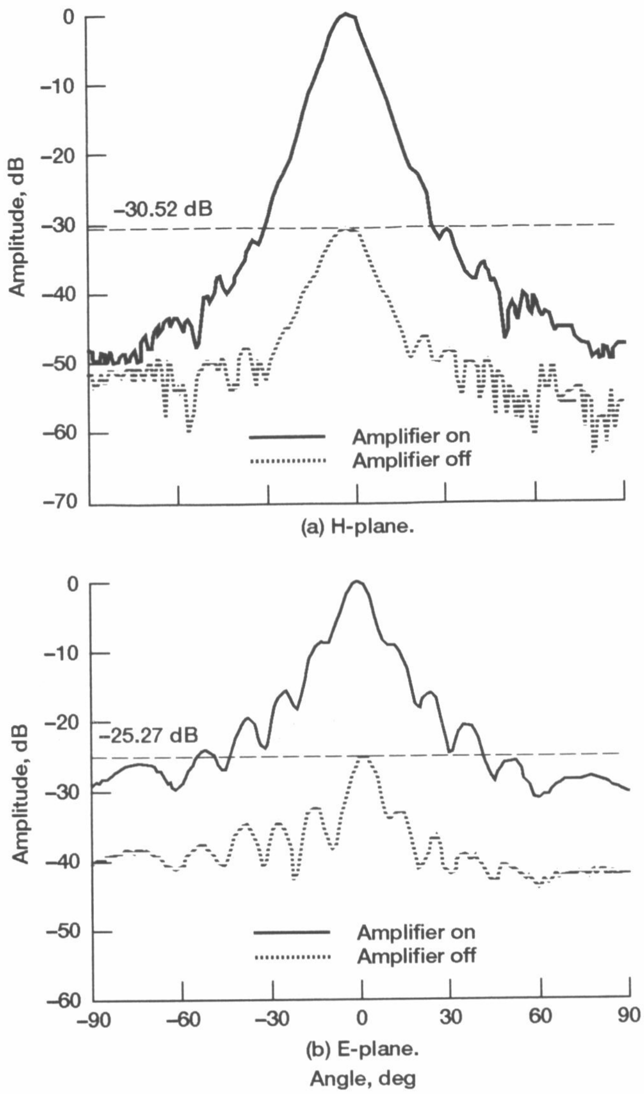

Figure 7.—The measured radiation pattern of the horn antenna showing space power amplification.

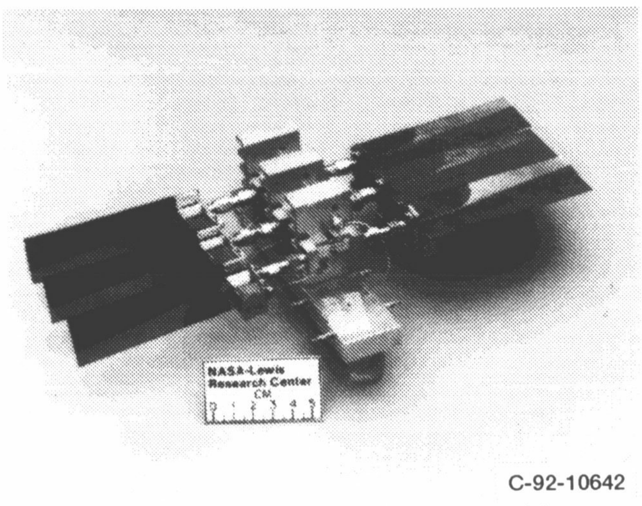

Figure 8.—The experimental three element LTSA MMIC array module.

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13. ABSTRACT ***(Maximum 200 words)***

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