lowed, such as: 1) the wavelengths are arranged in ascending order, 2) the pump power cannot exceed its maximum, e.g., 250 mW, 3) the minimum gain for signals is no less than 20 dB, etc. If the resulting gain fluctuation, the objective function, is less than the previous one, then the configuration is accepted. If not, a uniformly distributed number in the interval (0, 1) is generated and compared with $P(\Delta E)$:

$$P(\Delta E) = \exp(-\alpha \cdot \Delta E / T_p) \quad (3)$$

where ΔE is the resulting change of the gain fluctuation, and α is a coefficient ($\alpha = 0.004$ in our simulation). If the generated number is less than $P(\Delta E)$, the new configuration is retained. If not, the original configuration is used to generate the next displacement.

From the initial configuration (Fig. 2), we started the optimization process at a high temperature with $T_w = 2$ nm and $T_p = 2$ mW. At each temperature, essentially enough displacements (Basic Steps), e.g., 50, are performed. Then the system is cooled exponentially, $T_i^{(n)} = 0.9^n T_i$. If the expected number of acceptance (e.g., five) is not achieved at three successive temperatures, the optimization process stops.

Figure 3 is the resulting configuration. The gain fluctuation is optimized to within 1.7557 dB, significantly below 3 dB, and the average gain is above 22 dB. For the random principle of the algorithm, more trials as well as suitable parameters and an initial configuration could be employed to reach a more satisfactory result.

4. CONCLUSION

In conclusion, a new scheme for designing multiple pump Raman fiber amplifiers by the use of simulated annealing is presented. The configuration of a Raman fiber amplifier for a 64-channel WDM system with five laser diode pumps is demonstrated as an example. The algorithm can automatically yield a gain profile with a fluctuation of less than 1.8 dB in the amplification bandwidth of interest.

REFERENCES

1. M.-S. Kao and J. Wu, Extending transmission distance of high-density WDM systems using post transmitter fiber Raman amplifiers, *J Lightwave Technol* 9 (1991), 394–399.
2. D.N. Christodoulides and R.B. Jander, Evolution of stimulated Raman crosstalk in wavelength division multiplexed systems, *IEEE Photon Technol Lett* 8 (1996), 1722–1724.
3. H. Kidorf, K. Rottwitt, M. Nissov, M. Ma, and E. Rabarijaona, Pump interactions in a 100-nm bandwidth Raman amplifier, *IEEE Photon Technol Lett* 11 (1999), 530–532.
4. K. Mochizuki, Optical fiber transmission systems using stimulated Raman scattering: Theory, *J Lightwave Technol* LT-3 (1985), 688–694.
5. S. Kirkpatrick, C.D. Gelatt, Jr., and M.P. Vecchi, Optimization by simulated annealing, *Science* 220 (1983), 671–679.
6. R.L. Yang, Convergence of the simulated annealing algorithm for continuous global optimization, *J Optimiz Theory Appl* 104 (2000), 691–716.
7. G.P. Agrawal, Nonlinear fiber optics, P.F. Liao, P.L. Kelley, and I. Kaminow (Editors), Academic, San Diego, CA, 1995, 2nd ed.
8. C. Fludger, A. Maroney, N. Jolley, and R. Mears, An analysis of the improvements in OSNR from distributed Raman amplifiers using modern transmission fibres, *OFC Tech Dig*, Baltimore, MD, 2000, paper FF2.
9. R.H. Stolen, Polarization effects in fiber Raman and Brillouin lasers, *IEEE J Quantum Electron* QE-15 (1979), 1157–1160.

10 GHz GaAs MONOLITHIC TWIN-DIPOLE ANTENNA FET MIXER

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ABSTRACT: The first fully monolithic X-band twin-dipole antenna mixer consisting of a uniplanar twin-dipole antenna and a GaAs MES-FET single-gate mixer on the same GaAs substrate fabricated by monolithic microwave integrated-circuit technology (MMIC) is reported. The total chip size is $5 \times 5 \text{ mm}^2$. This circuit received an RF signal of 10 GHz, and down-converted it to an IF signal of 1 GHz with a conversion loss of 22 dB. The experimental results demonstrate that this topology has potential applications for future low-cost millimeter-wave receivers for smart munitions seekers and automotive-collision-avoidance radars. © 2001 John Wiley & Sons, Inc. *Microwave Opt Technol Lett* 30: 436–438, 2001.

Key words: GaAs; twin dipole; FET; antenna; mixer

INTRODUCTION

There is a considerable interest in the development of low-cost millimeter-wave receivers, transmitters, and imaging arrays for applications such as smart munitions seekers, aircraft landing systems, and automotive-collision-avoidance sensors [1–3]. The monolithic integrated-circuit approach, consisting of planar antennas directly integrated with amplifiers and mixers, offers several advantages over waveguide-based systems [4] at millimeter-wave frequencies. The monolithic integrated systems are smaller and less expensive to build than waveguide systems, and can be easily produced in high volumes for millimeter-wave applications. Different types of antennas integrated (hybrid or monolithic) with different solid-state devices, such as FETs, HBTs, Schottky diodes, and SIS devices, have already been demonstrated with excellent results. Hence, we are motivated to investigate the feasibility of integrating the twin-dipole antenna with a single-gate mixer by standard GaAs MMIC technology. The dipole antenna was chosen because of its simplicity of design and its wide bandwidth characteristic. The experimental results show that the twin-dipole antenna mixer could convert an RF signal of 10 GHz to an IF signal of 1 GHz with a conversion loss of 22 dB. The success of our experiment demonstrates that a complete monolithic wideband receiver or even a transceiver realized on one chip can be expected in the near future.

ANTENNA MIXER DESIGN

A photograph of our fabricated integrated antenna FET mixer is shown in Figure 1. The gate and source are connected to two finite grounds of a finite ground-plane coplanar waveguide (FGCPW) transmission line [5], while the drain is connected to the center of the FGCPW. The LO and RF signals are received by the twin-dipole antenna, and then

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applied to the input port (gate-to-source) of the MESFET through the balanced slot-line mode of the FGCPW. The IF output is extracted by the unbalanced coplanar mode of the FGCPW. The two parallel dipole antennas spaced a half-wavelength apart with a metal ground plane behind them produce a single centrally directed broadside lobe antenna pattern perpendicular to the GaAs substrate. Half-wavelength rather than full-wavelength dipole antennas were used in order to minimize the chip size. Since the FET is located midway between two dipole antennas, the distance between the FET and any one of the antennas is a quarter-wave-length. Thus, the balanced slot-line mode of the FGCPW can be used as quarter-wavelength transformers to fulfill the impedance matching between the twin-dipole antenna and the FET. A 0.1 nH inductor is inserted between the quarter-wavelength transformers and the MESFET to resonate out the imaginary part (gate-to-source capacitance C_{gs}) of the FET input impedance. The antenna mixer was designed at 10 GHz. The single-gate mixer is based on a four-finger (total gate width 200 μm) MESFET with 1 μm gate length. The MESFET device has 1.5 V knee voltage, 200 mA/mm I_{dss} , -1.7 V pinch-off voltage, and 160 mS/mm transconductance at $V_{gs} = 0$ V.

EXPERIMENTAL RESULTS

To achieve a higher degree of nonlinearity for frequency mixing, a gate-to-source bias voltage of -1.6 V near the pinch-off region is used. A drain-to-source voltage of 2 V is chosen to ensure that the FET is operated properly in the saturation region when the FET is turned on by the LO signal.

The experimental setup for the testing of the integrated twin-dipole antenna mixer is shown in Figure 2. The RF and LO signals are provided by an X-band horn antenna (antenna gain = 18 dBi), which is placed above the mixer 6 cm away in the direction of the main beam of the twin-dipole antenna. The IF power was measured by a GS Cascade Microtech probe at the output terminal of the FGCPW transmission line connected to the drain port of the FET. Since the direct measurement of the actual RF and LO

Figure 1 Photograph of the integrated twin-dipole antenna mixer fabricated by GaAs MMIC technology. Two half-wavelength dipole antennas are spaced a half-wavelength apart. The chip area is $5 \times 5 \text{ mm}^2$

Figure 2 Experimental setup for measuring the conversion gain of the receiver via on-wafer probing method

power level received by the twin-dipole antenna or the FET is not available at this time in our laboratory, the Friis transmission formula is used to obtain the available power received by the antenna. The twin-dipole antenna gain is calculated by IE3D software. The conversion gain is defined as the ratio of the IF output power dissipated in a 50 Ω load to the RF available power received by the twin-dipole antenna. In Figure 3, the conversion loss is plotted as a function of IF frequency under the conditions that the RF signal is fixed at 10 GHz and the RF and LO available power levels received by the antenna before entering the gate of the FET are fixed at 7.2 and 6.5 dBm, respectively. From this figure, it is clear that the IF signal peaks at 1 GHz with a mixer conversion loss of 22 dB. The large loss is suspected to be caused by the mismatch between the twin-dipole antenna and the FET. Figure 4 shows the measured results of the conversion loss versus LO signal (9 GHz) power level for a fixed RF (10 GHz) available power of 7.2 dBm before entering the gate port of the FET. Clearly, the conversion loss has not reached its saturation value, which means that a lower conversion loss still can be expected if the LO power is further increased or the mismatch between the antenna and the FET is improved.

CONCLUSION

The fully monolithic integration of an X-band twin-dipole antenna with a MESFET single-gate mixer on the same

Figure 3 Measured antenna mixer conversion gain versus IF frequency. $V_{DS} = 2$ V, $V_{GS} = -1.6$ V, RF freq. = 10 GHz, $P_{RF} = 7.2$ dBm, $P_{LO} = 6.5$ dBm

Figure 4 Measured antenna mixer conversion gain versus LO power level. $V_{DS} = 2$ V, $V_{GS} = -1.6$ V, RF freq. = 10 GHz, LO freq. = 9 GHz, IF freq. = 1 GHz, $P_{RF} = 7.2$ dBm

GaAs substrate is successfully demonstrated for the first time. This integrated antenna mixer exhibits a mixer conversion loss of 22 dB, which can be improved further by increasing the LO power level and impedance matching optimization. The success of our work suggests that this topology is promising for millimeter-wave receivers for smart munitions seekers and automotive-collision-avoidance radars, where the requirements for low cost, compact size, and wide bandwidth are needed.

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REFERENCES

1. A. Nesić, Integrated uniplanar antenna mixer and local oscillator, *Electron Lett* 27 (1991), 56–58.
2. H.H.G. Zirath, C.Y. Chi, N. Rorsman, and G.M. Rebeiz, A 40-GHz integrated quasi-optical slot HFET mixer, *IEEE Trans Microwave Theory Tech* 42 (1994), 2492–2497.
3. W. Chew and H.R. Fetterman, Printed circuit antennas with integrated FET detectors for millimeter-wave quasi-optics, *IEEE Trans Microwave Theory Tech* 37 (1989), 593–597.
4. H. Matsuura, K. Tezuka, I. Aoki, M. Yamanaka, S. Kobayashi, T. Fujita, A. Miura, and Y. Nagayama, Fully monolithic millimeter-wave mixer and IF amplifier with bow-tie antenna on GaAs substrate, *Electron Lett* 33 (1997), 1800–1801.
5. M. Riazat, I.J. Feng, R. Majidi-Ahy, and B.A. Auld, Single-mode operation of coplanar waveguides, *Electron Lett* 23 (1987), 1281.

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OPTICAL REGENERATION USING A FEEDFORWARD SEMICONDUCTOR OPTICAL AMPLIFIER WITH CHIRP-CONTROLLED FILTERING

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ABSTRACT: Optical pulse regeneration and reshaping using nonlinear optical pulse amplification followed by a chirp-controlled filtering is simulated. The nonlinear amplification and chirp control are obtained by feedforward current injection in a semiconductor optical amplifier. The nonlinear amplification provides pulse regeneration, and the controlled chirp, in association with an optical frequency discriminator, can be used to optimize the shape of several Gbit/s pulse streams. The simulator model has been confirmed experimentally using eye diagram techniques. In addition, the switching action of an optical semiconductor amplifier with a dynamically arbitrarily injected current can be simulated. © 2001 John Wiley & Sons, Inc. *Microwave Opt Technol Lett* 30: 438–442, 2001.

Key words: chirped optical regenerator; semiconductor optical amplifier; waveform shaping; optical pulse reshaping; optical remodulator; optical filtering

INTRODUCTION

The semiconductor optical amplifier (SOA) can be an alternative to costly wavelength-flattened erbium-doped optical amplifiers in wavelength-division multiplexing (WDM) networks [1], and is a promising device for add-and-drop links and wavelength routing. Besides providing optical signal amplification, the SOA can be employed for the regeneration and reshaping (2R) of optical pulsed signals after its degradation by the combined effect of fiber dispersion and nonzero signal bandwidth. Given a WDM channel, the 2R remodulation scheme detects the optical signal zero crossing, and conveniently reshapes the signal waveform [2]. The 2R remodulation can ensure that the level crossings of the optical pulses are recovered, amplified, and forwarded, providing bandwidth and protocol transparency. The technique is different from that of an optical repeater since the incoming pulses are reshaped without the need for a clock extraction circuit.

A 2R remodulator employing SOAs can be built using different techniques. In the interferometric technique [3], an optical decision circuit is implemented by placing one or two SOAs (polarized with distinct dc bias currents) inside the arms of a Mach-Zehnder interferometer (MZI). In this way, both wavelength conversion and 2R are achieved using the nonlinear transfer function of this SOA-MZI wavelength converter [4], with rates up to 80 Gbits/s [5]. An approach without MZI was implemented using an integrated

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