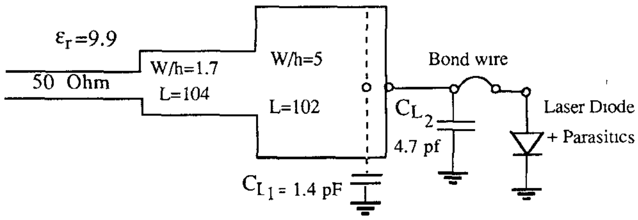


Fig 3. Layout of the novel step impedance matching circuit

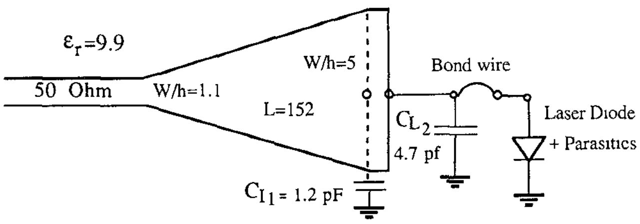


Fig 4 Layout of the novel taper impedance matching circuit

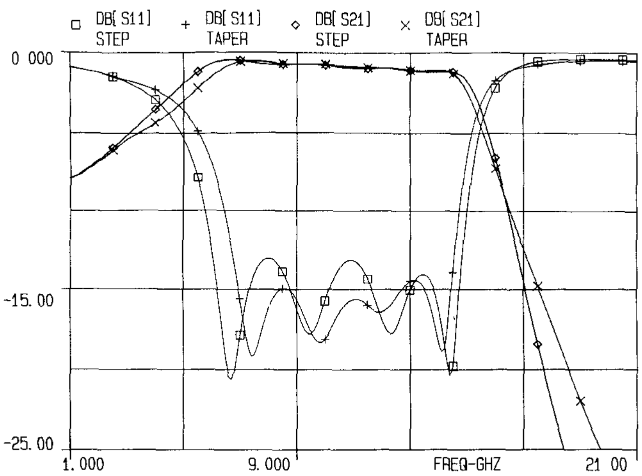


Fig. 5 Responses of the novel step and taper matching circuits

The responses of the novel matching circuits with step and linear taper distributed sections are shown in Fig. 5 and have nearly the same characteristics. The match is at a center frequency of 10.5 GHz with a bandwidth of about 9 GHz; in this band the return and insertion losses are better than 10 and 1.5 dB respectively.

Realization of this technique has not been carried out, as we do not have access to the identical diode discussed in [2]; however, work is in progress on matching other lasers. We anticipate that the hybrid implementation may suffer from additional inductances due to the bond wires used to attach the capacitors to the line, although these were accounted for in the CAD optimization [9]. A monolithic implementation will not face these problems.

## IV. Conclusions

A novel matching circuit technique which matches a 2 Ω laser diode and its parasitics to the 50 Ω line has been proposed. The matching circuits have a center frequency of 10.5 GHz, a bandwidth of 9 GHz, a reflection coefficient of better than −10 dB, and an insertion loss of less than 1.5 dB.

The step and linear taper transformers have almost the same response, which suggests that the scheme is not limited by configuration. This matching scheme may also be used to match other low-impedances devices, for example, IMPATT diodes, power FET's, and bipolar transistors.

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# An Infrared Fiber-Optic Radiometer for Controlled Microwave Heating

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***Abstract*—An infrared fiber-optic radiometer was used as a linear feedback element for noncontact temperature control of a microwave heating system. The temperature of water was monitored and maintained at about 42°C with a standard deviation of ±0.15°C and a maximum deviation of ±0.45°C. This controlled system would be very useful for medical, industrial, and domestic applications.**

## I. Introduction

Accurate low-temperature (20–50°C) monitoring and control in the presence of a strong microwave (MW) field are needed in medical applications such as hypothermia [1] and hyperthermia [2]. In general, when fast volume heating is needed, MW's can be used. However, the use of conventional temperature sensors for monitoring and controlling the MW heating is complicated in a strong electromagnetic field environment.

Because of their insensitivity to electromagnetic fields, fiber-optic temperature sensors may be one way to overcome this problem. Two of the possible approaches that incorporate optical fibers are fluoroptic™ thermometry [6] and infrared (IR) radiometry [3]. The main difference between those methods is that fluoroptic thermometry requires contact between phosphor and sample while radiometry is a noncontact method. A surface of temperature $T$ emits infrared radiation of intensity $I = AT^4$, where $A$ is a constant. Radiometric measurements of $I$ serve for an accurate determination of $T$. These measurements may well be performed via infrared-transmitting optical fibers.

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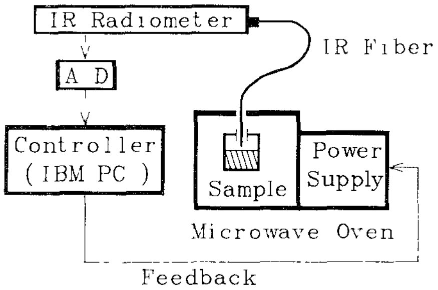


Fig. 1 IR fiber-optic radiometer as used for monitoring and controlling the temperature in a microwave field

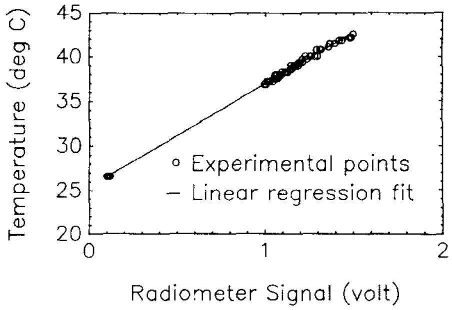


Fig. 2 Temperature measured by a thermocouple versus the radiometer output voltage

In [3], [4], and [5] we discussed the theoretical background of noncontact IR fiber-optic radiometry and described a radiometer which is capable of measuring temperatures lower then 30°C. In this work we have used such a radiometer to achieve very stable temperature control of a sample heated by a microwave field.

## II. Experimental System

The experimental system is shown in Fig. 1. We used a simple domestic microwave oven. A heating current was continuously applied to the magnetron cathode. The output power was switched by turning the electric field of the magnetron on and off. A zero cross detector was used as a switch in order to prevent switching noise. The sample was 200 $cm^3$ of water in an ordinary glass. The distal end of a 1-m-long silver halide infrared-transmitting fiber was inserted into the oven through a normal ventilation hole and positioned rigidly a few millimeters above the water surface. The infrared radiation was measured by a pyroelectric detector. The radiometer output voltage was fed through a 12 b A/D converter into an IBM PC which served as a temperature controller.

In this work we used two control techniques:

1) On/off mode: The power was turned on or off when the temperature of the sample was lower or higher than the set point.
2) Pulsed mode (repetition rate modulation): The average power was controlled by the repetition rate of the power pulses.

In order to calibrate the radiometer, the sample was placed in the microwave oven, and a thermocouple was placed adjacent to the fiber tip. Several readings were taken from both the thermocouple and the radiometer. The thermocouple was then removed, and the oven power turned on. After the set point was reached and maintained for 10 to 20 min, the oven power was turned off and the thermocouple reinserted. Again readings were taken from both the thermocouple and the radiometer as the sample cooled. In this way we acquired enough points to make an adequate calibration.

## III. Results

The calibration results are shown in Fig. 2. The point in the lower left corner was measured prior to the heating. In this range of temperatures the radiometer signal was found to be linear with temperature, as expected [3]. The minimum resolvable temperature difference was 0.1°C. The calibration accuracy was 0.5%, resulting in a systematic temperature error of ±0.2°C.

The results of the temperature control using the two techniques are illustrated in Figs. 3 and 4 and are summarized in Table I.

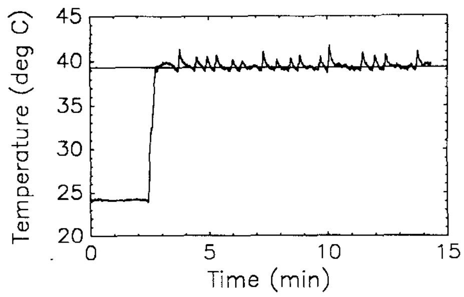


Fig. 3 Calibrated radiometer temperature measurement versus time, as recorded in the on/off control mode. The solid horizontal line is a set point.

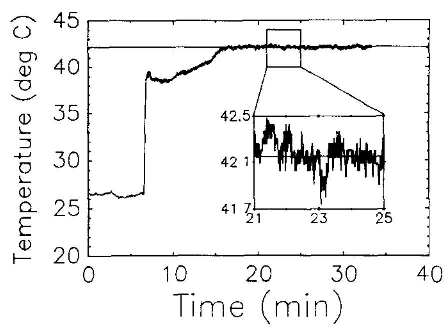


Fig. 4 Calibrated radiometer temperature measurement versus time, as recorded in the pulsed control mode. The solid horizontal line is a set point. The insert shows the extent of temperature fluctuations during the control

TABLE I
Results of ON/OFF and Pulsed Control Modes

| | on/off °C | Pulsed °C |
|---|---|---|
| Set - Point | 39.3 | 42.15 |
| Std. Dev. from the Set - Point | 0.5 | 0.15 |
| Max. Dev. from the Set - Point | 2.5 | 0.45 |

## IV. Discussion

The output power of our microwave oven was 500 W, which resulted in a very rapid heating of the small sample ( ≃1°C/s in the 20–40°C range). Thus the need for a temperature sensor with fast response is clear. In regular temperature control systems, deviations from the set point are related to the time delay in system response or to nonuniform heating. Taking into consideration that the surface temperature of the sample was probably different from the temperature in deeper layers and that the response time of the whole system was about 0.5 s, the relatively large overshoots seen in the on/off mode (Fig. 3) can be understood. However in the pulsed mode, the refinement of power control (by repetition rate) leads to much smaller overshoots (Fig. 4).

## V. Summary

In this work we demonstrated that an IR fiber-optic radiometer is an accurate, simple, linear, and fast response device that can be used as a noncontact temperature sensor in a MW heating control system. Using this fiber-optic-based radiometer system, we succeeded in stabilizing a temperature of about 42°C with a standard deviation of $\pm 0.15$°C in a microwave heating environment. This specific temperature was chosen because of its relevance in medical applications. Control at higher temperatures presents less of a problem because the infrared emission is much stronger. The control method described here is novel, and it is potentially very useful for medical and industrial applications.

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# InGaAsP DC-PBH Semiconductor Laser Diode Frequency Response Model

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***Abstract*—A simple and accurate model for the frequency response of InGaAsP double-channel planar buried heterostructure semiconductor laser diodes intensity modulated in the microwave range is presented. It is shown that the parasitic capacitance associated with the reverse-biased blocking junction can significantly reduce the 3 dB modulation bandwidth. The results obtained and alternatives to improve the high-frequency performance are discussed and compared to experiments.**

## I. Introduction

InGaAsP double-channel planar buried heterostructure (DC-PBH) semiconductor laser diodes are important sources for optical communication systems operating at wavelengths of 1.3 and 1.55 $\mu$m, where the dispersion and the losses in conventional optical fibers have their minima, respectively. Significant improvements in the static characteristics of these lasers have been obtained in the last decade, such as low threshold currents, high quantum efficiency, linearity of light versus current characteristic, operation at high optical power, and long-term reliability. One of the main reasons for this good static performance is the efficient lateral carrier confinement achieved when leakage current blocking junctions are produced outside the active region. In the InGaAsP DC-PBH lasers this is achieved by growing p–n–p–n layers in both sides of the active region. As a result, the p–n junctions reverse biased are very effective in reducing the static leakage current. However, the parasitic capacitance associated with the p–n junctions can significantly degrade the frequency response of these lasers when intensity modulated in the microwave range [1]–[6]. In order to achieve wide-band modulation, besides the optimization of the packaging parasitics and of some active region laser parameters [7]–[9], the parasitic capacitance must be decreased.

In this paper, an equivalent electrical circuit for the laser parasitics is described and its relevant parameters are estimated. Then, using a complete equivalent circuit for the intrinsic laser with its parasitics and using the SPICE 2G program, the DC-PBH laser frequency response is predicted and compared to measurements. The results obtained and ways to improve the high-frequency performance are discussed. These results can be useful for modulation bandwidth improvement of Fabry–Perot (FP) and distributed feedback (DFB) DC-PBH lasers.

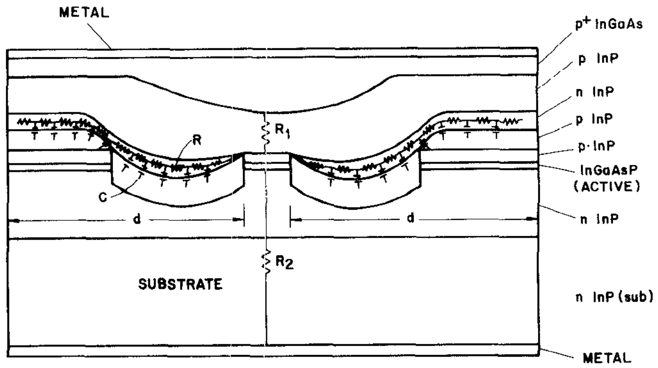


Fig 1. Schematic structure for the InGaAsP DC-PBH laser

## II. Laser Parasitics Equivalent Circuit and Frequency Response

The schematic structure of the InGaAsP DC-PBH laser ($\lambda \sim 1.3$ $\mu$m) is represented in Fig. 1. In this, the blocking junction distributed $RC$ ladder network is also indicated.

The laser active region equivalent circuit suitable for nonlinear modeling has already been described by other authors [7]–[9]. Here, the equivalent circuit for the DC-PBH parasitics and its frequency response are described. The frequency response of the overall laser is a combination of the parasitic network and the intrinsic laser. The package (or mount) parasitics will be assumed negligible, since the lasers are expected to be mounted in microwave packages, with very large bandwidths. Under normal operating conditions the intrinsic laser is forward biased and the p–n junction between the upper n-InP layer and the p-InP layer below it is weakly reverse biased, reducing dc leakage current. The associated junction capacitance can be quite large as it usually extends across the entire area of the laser diode. This is

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