Engineering Journal of University of Qatar, Vol. 10, 1997, p. 109 - 121

OPTICAL MATCHING FOR MICROWAVE ACTIVE DEVICES

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ABSTRACT

This paper describes a microstrip optically controlled matching technique between microwave active devices with low impedance (less than 10 ohms) and a conventional 50 or 70 ohm communication system in the upper microwave and mm-wave frequencies. The bandwidth is 20 GHz, the maximum insertion loss is less than 1.5 dB and the reflection coefficient is less than -7 dB. The laser controlled terminal impedance's can be changed and adjusted by choosing the carriers lifetime of the semiconductor substrate and by changing the power and wavelength of the optical source.

Keywords: Microstrip, Microwave matching, Photoconductivity, Taper line.

INTRODUCTION

Tapered microstrip transmission lines are widely used for matching in the microwave range of frequency. Multisection quarter-wave transformers and tapered transformers and tapered transmission lines [1] are based on the fact that the end impedance's of the line are the same as that of the source and the load. The taper impedance profile can be either linear, exponential, hyperbolic, parabolic or according to Willis-Sinha profile [2]. Due to the need for optically controlled phase array antennas and optical communication systems, laser diodes and high frequency microwave active devices are currently used. Hence raised the problem of wide-band matching between 50 or 70 ohm systems to a very small impedance of the active device or laser diode (about 2-10 ohms). This low impedance value is a problem in microstrip sections because it requires a very wide line (shape ratio W/H > 25 for substrates with ε_r = 9.8 and W/H >18 for ε_r =12), where W is the line width and H is the substrate height. Such wide lines will cause excitation of higher order modes [3]. Introducing a series resistance to match between the line and the active devices or laser diode will dissipate more than 70% of the transmitted power resistance to match between the line and the active devices or laser diode will dissipate more than 70% of the transmitted power [4], so it is considered a power dissipating technique. Reducing the microstrip line impedance using lumped shunt capacitors at either ends of the taper line is analyzed in [5]. The authors made transformation from 50 ohms to 17.5 ohms using microstrip tapered line. Further reduction of end impedance is completed by extra line length in addition to the lumped capacitors at either end. The line length is changed and the lumped element capacitor will be a source of wave distortion due to the bond wires.

In this work, modification of the end impedance and reduction of the taper line terminal impedance is achieved by laser excitation longitudinally in direction of propagation as shown in Fig.1. The induced photo-conductivity profile will modify the line impedance gradually. In this way no lumped elements are used to change the end impedance of the taper and the line length is not changed by using multi-sections. This technique can change any terminal impedance to any desired value by changing the laser power and the laser wave length or by changing the substrate materials.

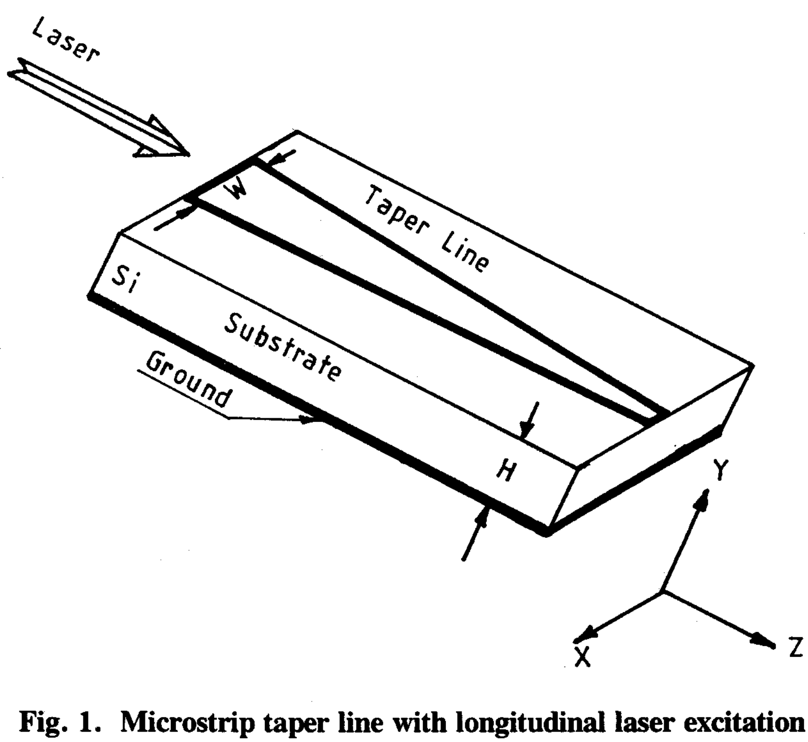

Fig. 1. Microstrip taper line with longitudinal laser excitation

ANALYSIS OF PHOTO-CONDUCTIVITY PROFILES

The taper line is designed to match between 50 to 25 (or 70 to 50) ohms on a semiconductor substrate as shown in Fig.1. When an optical excitation is applied, an in-homogeneous distribution of conductivity is built up longitudinally in z direction as shown in Fig.2. In case of low power laser source this conductivity profile $\Delta\sigma(z)$ is given by [6].

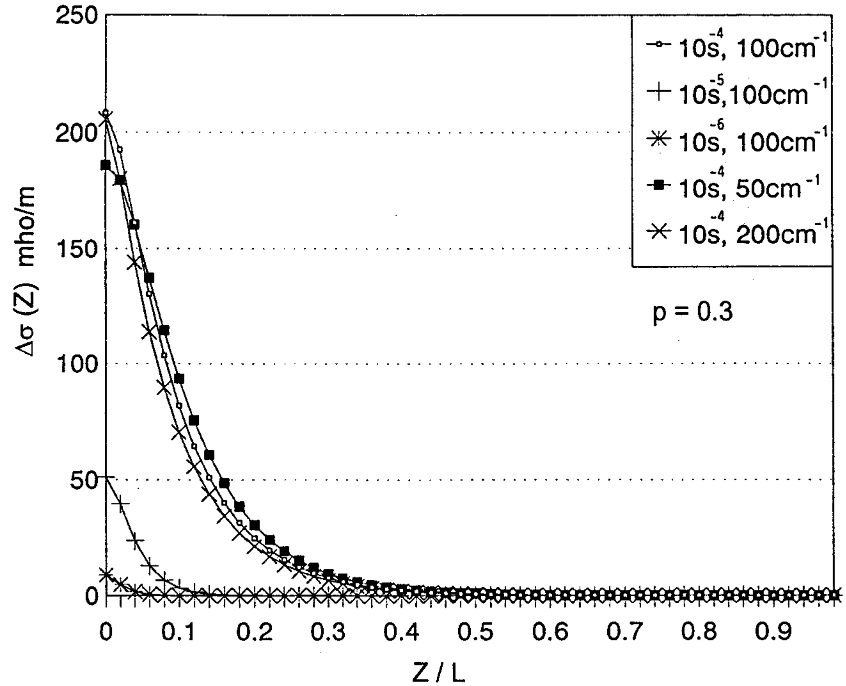

Fig. 2. Induced photo-conductivity profiles along the line

$$\Delta\sigma(z) = \left(\frac{\Delta\sigma_o}{1-M^2}\right)\left[\exp(-\alpha_r z) - \left(\frac{ML_a + L}{L + L_a}\right)\exp(-z/L_a)\right] \quad (1)$$

$$\Delta\sigma_o = F_1 F_2 \frac{e\lambda_p}{hc}\left[\mu_e S \tau \alpha_r (1-R)\left(\frac{P}{A}\right)\right] \quad (2)$$

$$L_a = \left[2\mu_p \mu_n \tau V_T / \mu_n\right]^{1/2} \quad (3)$$

where $M=\alpha_r L_a$, $L=\tau v$, $\mu_e=\mu_n+\mu_p$, $V_T=kT/e$

α is the radiation absorption coefficient and it depends on the optical wavelength λ, v is the surface recombination velocity, h is Planck's constant, c is the velocity of light in free space; R is the surface reflectivity; and S is the relative spectral response of the material exhibiting a peak at λ_p (α, R and S depend on the optical wavelength), P is the optical power and A is the illuminated area. μ_n and μ_p are the mobility s of electronics and holes respectively, τ is the carriers life time; k is Boltzmann's constant; T is the absolute temperature, e is the electron charge and L_a is the ambipolar diffusion length and $\Delta\sigma o$ is the initial conductivity at z = 0. Factor F_1 is due to absorption and surface recombination, while the factor F_2 incorporates the effect of carriers diffusion in the regions surrounding the area of optical excitation [6]. For short optical wavelength M >> 1 and consequently the plasma depth $d_e \approx L_a$.

In case of long optical wave length M << 1 the plasma depth in z-direction $d_e \approx 1/\alpha_r$. The profile in the x-direction is given by [6]:

$$\Delta\sigma(x) = \Delta\sigma_m\left[1-\exp\left(w/2L_a\right)\cosh\left(x/2L_a\right)\right] \quad 0<x<w/2 \quad (4)$$

$$\Delta\sigma(x) = \Delta\sigma_m\left[\exp(-x/2L_a)\sinh(w/2L_a)\right] \quad w/2<x<\infty \quad (5)$$

where $\Delta\sigma_m$ is maximum conductivity. Assuming that the optical line width w is equal to the line width W, the conductivity profile in the x-direction can be approximated by the step shown in Fig.3, and in this case we can consider that the area under the strip (WxH) is approximately homogeneously illuminated by the laser radiation. In the case of low power laser, we considered the carriers lifetime and mobility s are independent of excess carries density. But in case of high laser power the carriers lifetime and mobility s will be dependent on generated carriers density and the conductivity profile is obtained from solving the diffusion equation in the steady state [7].

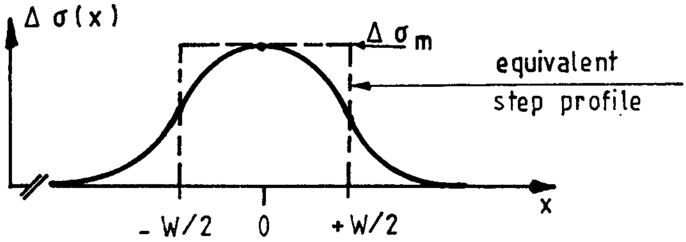

Fig. 3. Lateral profile of photo-conductivity

$$L_a^2 \Delta'' n(z) = \Delta n^2(z)/n_i + \Delta n(z) - \Delta n(0)\exp(-\alpha_r z) \tag{6}$$

where n_i is the original carriers concentration and $\Delta'' n(z)$ is the second derivative of induced carriers concentration with respect to z and

$$\Delta n\,(0) = [\Delta \sigma_o / (e\,\mu_e] \tag{7}$$

CHARACTERISTIC IMPEDANCE AND PROPAGATION CONSTANT

The total effective loss tangent T_{eff} due to the photo-excited semiconductor is :

$$T_{eff}(z,f) = \left(\frac{\varepsilon_r q_e(z)}{\varepsilon_{eff}(z,f)}\right) \cdot \left(\frac{\varepsilon_r}{\varepsilon_r} + \frac{\sigma_d + q_p \Delta\sigma(z)}{\varepsilon_0 \varepsilon_{r\varepsilon} \omega}\right) \tag{8}$$

For small values of original conductivity σ_d, and negligible conductor and dielectric losses, the effective T_{eff} of the excited substrate is approximated by [8] :

$$T_{eff}(z) = q_e(z) q_p(z) \Delta\sigma(z) / \varepsilon_0 \varepsilon_{eff}(z)\omega \tag{9}$$

where the total conductivity is $\sigma(z) = \sigma_d + \Delta\sigma(z)$

ε_r and ε_r are the real and imaginary parts of relative permittivity, α is the operating microwave frequency, q_e is the dielectric filling fraction and q_p is the plasma filling fraction, ε_0 is the free space permittivity and ε_{eff} is the effective dielectric constant and it is given by :

$$\varepsilon_{\text{eff}}(z,f) = \varepsilon \frac{\varepsilon - \varepsilon_{\text{eff}}(z,0)}{1-\left(f/f_{50}\right)^{m}} \tag{10}$$

Where ε is the relative dielectric constant, ε_{eff} (z,o) is the zero frequency value of ε_{eff} at any length z on the line. f_{50} is the 50% dispersion point as explained in [9]. The dielectric filling factor $q_e(z)$ is a function of ε and the ratio W/H [10,11] which is z-dependent. The new characteristic impedance Z(z) and the propagation constant at any section z are approximated by :

$$Z(z) = Z_0(z)/[1-j\,T_{eff}(z)]^{1/2} \tag{11}$$

$$\gamma(z) = \alpha(z) + j\beta(z). \tag{12}$$

where $\alpha(z)$ and $\beta(z)$ are the attenuation and phase constants respectively, and are given by (11).

$$\alpha(z) = A(z)\,[B(z)-1]^{1/2} \tag{13}$$

$$\beta(z) = A(z)\,[B(z)+1]^{1/2} \tag{14}$$

where :

$$A(z) = \omega\left[\mu_o \mu_r \varepsilon_o \varepsilon_{eff}(z)\right]^{1/2}$$

$$B(z) = \left[1 + T^2_{eff}(z)\right]^{1/2}$$

REFLECTION COEFFICIENT PATTERN

The taper line is divided to N sections of equal lengths Δz Fig.4. The impedance and the propagation constant is considered fixed for each small section and is equal to the corresponding average value within the section. If the reflection coefficient between each two successive section < 0.2, small reflections theory [2] can be applied using the approximate relation for the total reflection coefficient:

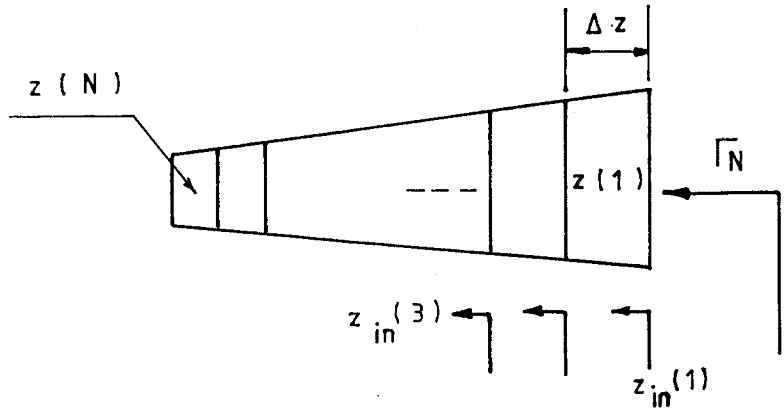

Fig. 4. N sections of equal lengths Δz

$$\Gamma_N = \sum_{n=1}^{N-1} \Gamma_n \cdot \left(\prod_{i=1}^{n} \exp[-2(\alpha_i + j\beta_i).\Delta z]\right)$$
$$\text{where } \Gamma_n = \frac{Z(n) - Z(n+1)}{Z(n) + Z(n+1)} \tag{15}$$

Γ_n is the reflection coefficient between (n) and (n+1) sections, αi and βi are the attenuation and phase constants in the i- th section. In case of large reflections the exact method is used. The total input impedance is evaluated shifting from section to the other using the relation.

$$Z_{in}(n) = Z(n).\frac{Z_{in}(n+1) + Z(n)\tanh(\gamma_n \Delta z)}{Z(n) + Z_{in}(n+1)\tanh(\gamma_n \Delta z)} \tag{16}$$

$$\Gamma_N = \frac{Z_{in}(1) - Z_0}{Z_{in}(1) + Z_0} \tag{17}$$

where Z_o is terminal load impedance at which total input impedance $Z_{in}(1)$ is evaluated.

RESULTS AND DISCUSSION

For a Si substrate having the following parameters $\varepsilon_r = 12$, $\mu_e = 1500$ cm^2/vs, $\mu_p = 600$ $cm^2/v.s$, $R = 0.3$, $v_s = 50$ cm/ s, at center frequency 10 GHz, the modified impedance profiles along the line are shown in Figs. 5, 6 and 7, for different optical power levels and for different material lifetimes. It is clear that large lifetime has great effect in changing the characteristic impedance profile which vary gradually from 25 to 6.5 ohms when $\tau = 10^{-4}$ s and optical power is 0.06 watts. Adjustment for specific values can be achieved by optical power changes for the same substrate material. If the lifetime is 10^{-6} s for the same optical power level the terminal impedance can be changed from 25 to about 17 ohms, and can be less according to the used laser power. If the substrate lifetime is large the photo-conductivity profile penetrates deeper and the impedance changes are more smooth. The maximum attenuation constant $\alpha(z)$, occurs at maximum conductivity, is 6 NP/m when the optical power is 0.02 W, $\tau=10^{-4}$ s. The maximum value of α can be controlled by optical power and

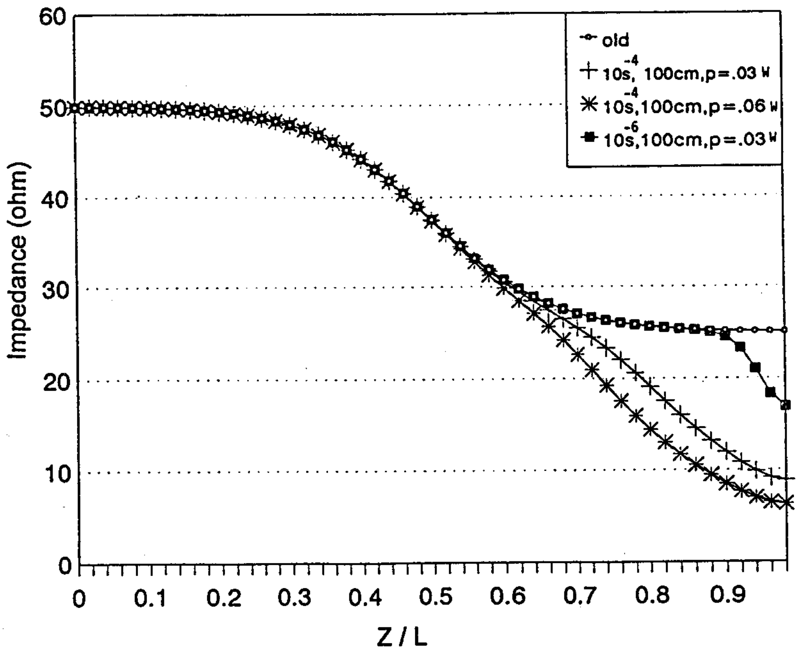

Fig. 5. Impedance profiles for different laser power and for different carriers lifetime. $\alpha_r=100$/cm, 50-25 ohm taper line

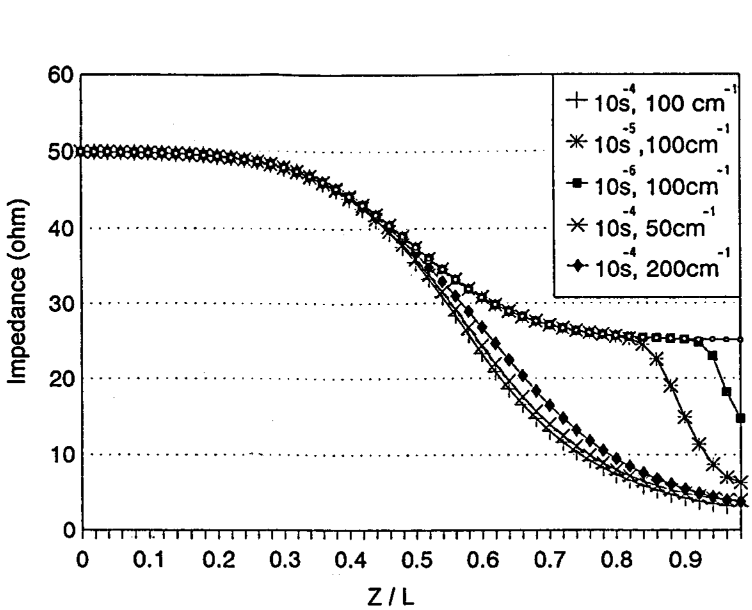

Fig. 6. Impedance profiles for different τ and α_r at P = 0.3 W

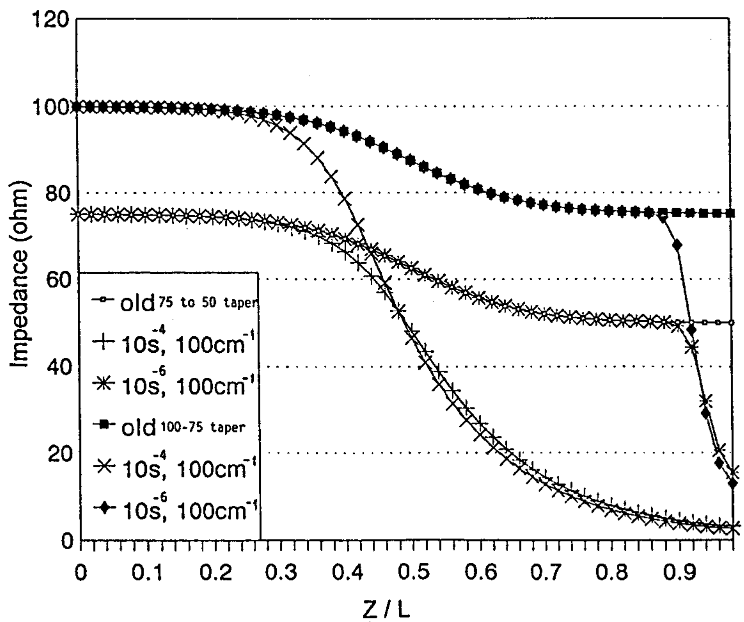

Fig. 7. Impedance profiles before and after optical excitation (75-50 ohm . taper line)

material lifetime (Fig.8). Maximum total insertion loss is 27% (less than 1.5 dB). The reflection coefficient is less than 0.2 and the useful bandwidth is greater than 20 Hz as shown in Fig. 9. It is obvious that carriers lifetime has enormous effect on the reflection pattern and the useful bandwidth. Table 1 illustrates a comparison between the results of this work and that of reference [5].

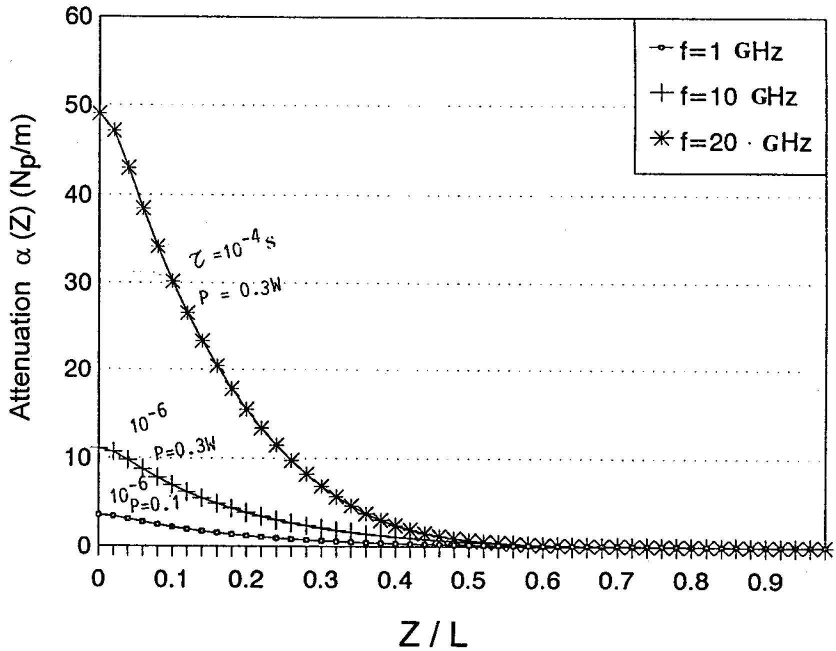

Fig. 8. Attenuation profiles at different frequencies

In this optical technique different terminal impedance's can be adjusted using variable laser power. Optical devices are effective and flexible, specially when the laser diode is low noise source and when material parameters allow low power applications. On the other hand using lumped capacitor with wire bond to the taper line in reference [5] are sources of increased losses and reflections. Meanwhile in this optical technique impedance profile changes in a smooth gradual way and consequently losses and reflections are low.

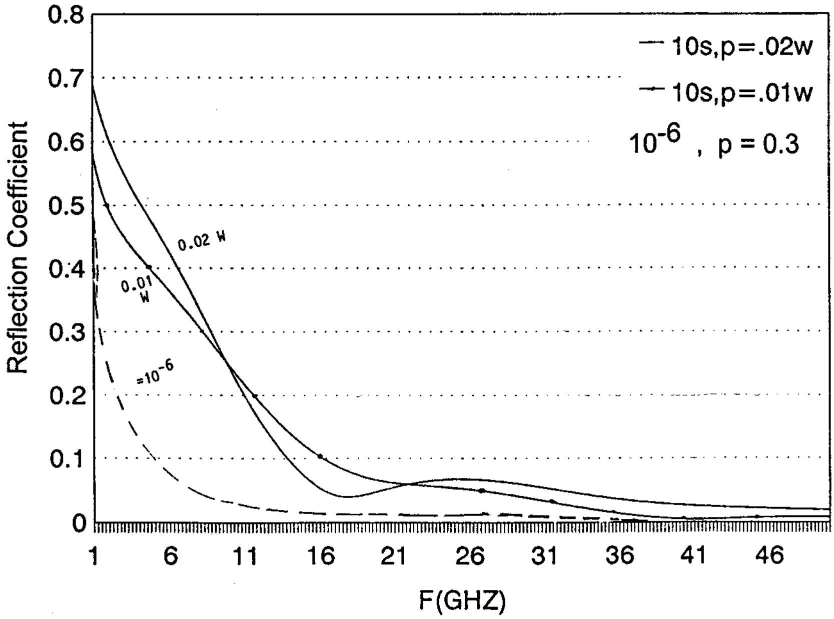

Fig. 9. Reflection pattern at different laser powers

Table 1. Comparison Between the Results of This Technique and That of Technique Used in [5]

This Work (Optical Technique)			
Parameter	Maximum	Minimum	Technique of Paper [5]
Total Insertion Loss	1.25 dB at $P = 0.3W$ and $\tau = 10^{-4}s$	0.224 dB at $P = 0.1W$ and τ $10^{-6}s$	1.5 dB
Total Reflection Coefficient	-12 dB	-26 dB	-10 dB
Effective Bandwidth	12 GHz	20 GHz	9 GHz

CONCLUSIONS

From these successful results, we conclude that modifying any matching section using optical radiation is an efficient technique which gives gradual smooth impedance profile to match low impedance values. The technique is applicable for microwave active devices, laser diodes in optical communication systems and in active antennas. The desired profile is controlled by choosing the substrate semiconductor material (Si, GaAs or InP.) and its lifetime, absorption coefficient and the optical power with its wave length. No need for using lumped elements to match different terminal impedance's. The insertion loss is very small and the reflections are negligible, and the system used is flexible and efficient.

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