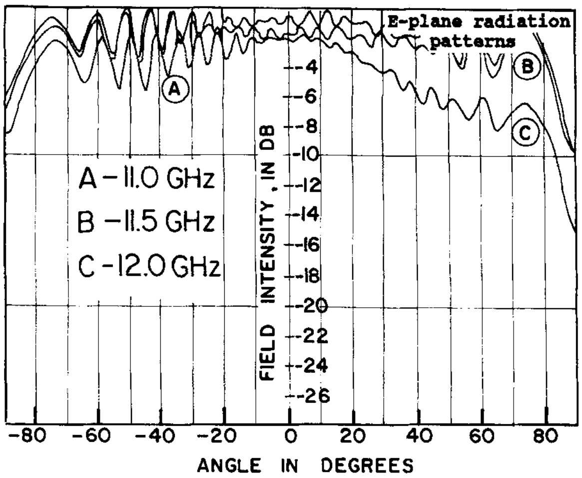

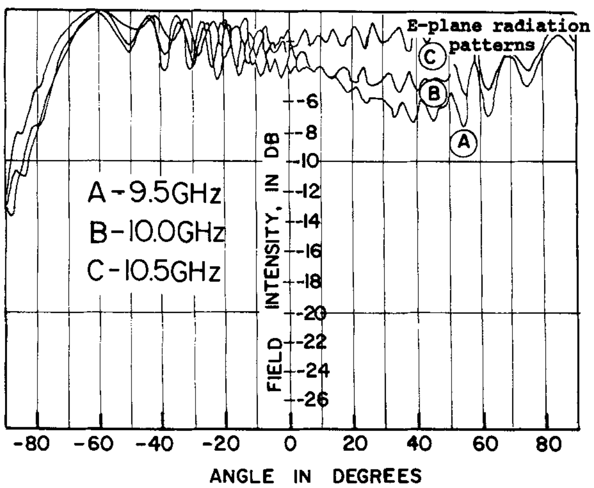

Figure 4 Measured E-plane radiation patterns at 9.5, 10.0, 11.0, 11.5, and 12.0 GHz

In order to smooth the E-plane radiation pattern, the space between two radiating slots was taken as small as possible (3 mm in the X-band case). The resonance frequencies of two adjacent slots were chosen as shown in Figure 2. In zero-order approximation, neglecting mutual coupling and an effect of small spacing, both reactances are connected in series, and their total resultant reactance will be an algebraic sum of individual reactances of each slot. Curves A and B in Figure 2(a) correspond to reactances of slots referred to the plane at the middle between two slots. Proper choice of $f_{\text{res},1}$ and $f_{\text{res},2}$ leads to the reactance cancellation of both slots at three frequencies (f_1, f_0 and f_2). The broadbanding action of the short-circuited waveguide stub with length close to $1/2\lambda_g$ at f_0 is demonstrated in Figure 2(b). Finally, special measures were undertaken to reduce mutual coupling between the slots.

The resultant theoretical and experimental VSWR and the measured E-plane radiation patterns are plotted in Figures 3 and 4, respectively. The measured VSWR is less than 2.5 : 1 in 8.18 GHz to 12.05 GHz frequency range (38.25%). The E-plane radiation patterns are free from nulls in angle range $\pm 45°$ around broadside at frequencies from 9.5 GHz to 12.0 GHz.

The resultant double-slot waveguide radiator can be fed from the underside using a standard coaxial-to-waveguide transition. The total length of the radiator in the E-plane is about 0.8 of the free-space wavelength at the highest operational frequency.

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LIGHT AMPLIFICATION USING BACKWARD RAMAN PUMPING

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KEY TERMS

Optical communications, scattering

ABSTRACT

Analytical expressions for backward Raman amplification using pulse pumping are presented. We find that pulse pumping results in higher amplification gain than CW pumping and there exists an optimum pumping length at which maximum gain occurs. The results can be extended to CW pumping.

INTRODUCTION

Stimulated Raman scattering can be used to provide optical amplification in optical fiber communication systems. Recently, several experiments with pulse or CW pumping were reported in the literature. [1–5] Forward and backward pumping structures can be used in fiber Raman amplifiers. When pulse pumping is used, it is advantageous to adopt backward pumping since to time synchronization between the pump and the signal pulses is required. In this letter, we present analytical expressions for backward Raman amplification using pulse pumping. The result shows that high-power density pulse-pumping sources can have higher amplification gain than CW or low-power density pulse-pumping sources.

ANALYSIS

Consider a single-mode fiber with length L. The signal pulses are injected at $z = 0$ and travel in the $+z$ direction while the pump pulses with amplification P_L, width W, and period T are injected at $z = L$ and propagate along the $-z$ direction. Let α_s and α_p be the loss coefficients of the signal and the pump and let g and A denote the Raman gain constant and the effective Raman cross section, respectively.

In order to simplify the problem, we assume that pump depletion is negligible. Let N be the number of pump pulses that a signal pulse will encounter during its propagation through the fiber. Then N is given by

$$N = \frac{L}{T}\left(\frac{1}{v_p} + \frac{1}{v_s}\right) \tag{1}$$

where v_s and v_p are the group velocities of the signal and the pump, respectively. The first tern on the right-hand side of Eq. (1) is the number of pump pulses already in the fiber when the signal pulse emits at $z = 0$ and the second term is the number of pump pulses injected at $z = L$ while the signal propagates through the fiber.

Since the signal encounters N pump pulses during its propagation through the fiber with length L, the interval between the encounter point of two successive pump pulses is the same. Assume $N \gg 1$. Then this interval D can be obtained as

$$D = \frac{L}{N} = \frac{Tv_s v_p}{v_s + v_p} \approx \frac{Tv_p}{2} \tag{2}$$

Here we assume the difference between v_s and v_p is negligible.

For convenience we assume that a particular signal pulse meets the first pump pulse at $z = D$. Then the signal will meet the ith pump pulse at $z_i = iD$, and at this point the pump amplitude is $P(z_i) = P_L e^{\alpha_p(z_i - L)}$. Because the signal pulses travel along the opposite direction of the pump pulses, the interaction length for the signal and the ith pump pulse is $L_t = v_p W/2$. The signal gain obtained from the ith pump pulse is given by [6]

$$G_i' = \exp\left[\frac{gp(z_i)L_t}{A}\right] \tag{3}$$

However, between each two successive pump pulses the signal has the propagation loss $e^{-\alpha_s D}$. Hence the net gain is

$$G_i = \exp\left[\frac{gP(z_i)L_t}{A} = \alpha_s D\right] \tag{4}$$

The total gain is given by

$$G = \prod_{i=1}^{N} G_i = \exp\left[\frac{gv_p P_L W}{2A}\frac{1 - e^{-\alpha_p L}}{1 - e^{-\alpha_p D}} - \alpha_s L\right] \tag{5}$$

DISCUSSION

There exists an optimum pumping length L_{opt}, where maximum signal gain occurs. From Eq. (5) we can obtain L_{opt} as

$$L_{opt} = \frac{1}{\alpha_p}\ln\left\{\frac{\alpha_p}{\alpha_s}\left[\frac{gv_p P_L W}{2A(1 - e^{-\alpha_p D})}\right]\right\} \tag{6}$$

When $T = W$ and $e^{-\alpha_p D} \approx 1 - \alpha_p D$, then G becomes

$$G = \exp\left[\frac{gP_L}{A\alpha_p}(1 - e^{-\alpha_p L}) - \alpha_s L\right] \tag{7}$$

which is the same as the CW case derived by Mochizuki [7].

Let $P_0 = P_L W/T$ be the average pump power. Then Eq. (5) becomes

$$G = \exp\left[\frac{gv_p P_0 T}{2A}\frac{1 - e^{-\alpha_p L}}{1 - e^{-\alpha_p D}} - \alpha_s L\right] \tag{8}$$

For fixed P_0 and W, the variations of G and L_{opt} with respect to T are shown in Figure 1, where the system parameters are as follows: $A = 5 \times 10^{-11}$ m^{-2}, $g = 7.5 \times 10^{-14}$ m/W, $v_p = 2 \times 10^8$ m/s, $\alpha_p = 0.9$ dB/km, and $\alpha_s = 0.8$ dB/km. When the ratio of T and W is small, G is almost independent of T; but G increases rapidly with T when the ratio is large. For equal average pump power P_0, the results shows that pulse pumping can obtain higher gain than CW pumping, and high-power density with long period pulse-pumping sources result in higher gain than low-power density with short period ones. On the other hand, L_{opt} also increases with T.

For fixed P_L and W, since the number of pump pulses encountered by the signal becomes less as T/W increases, G decreases rapidly as T/W increases as shown in Figure 2. The decreasing of L_{opt} is also shown in the same figure.

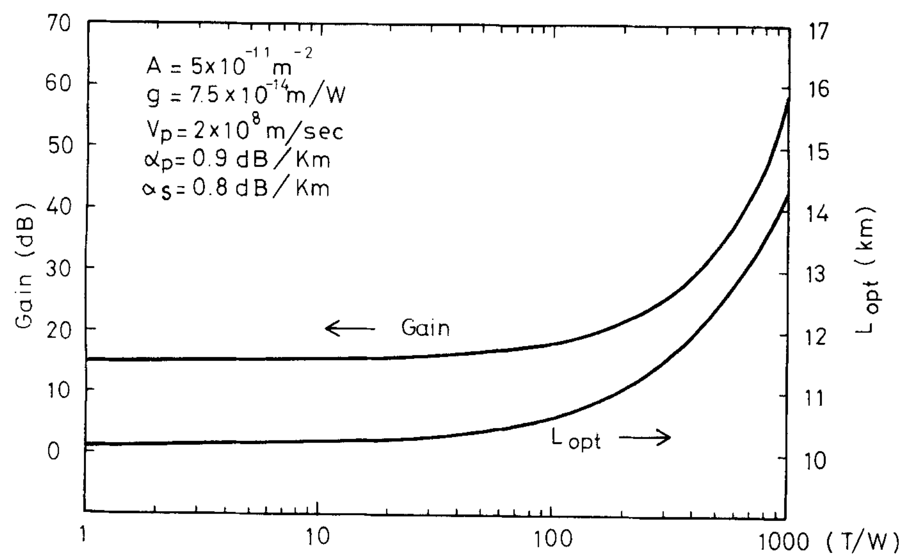

Figure 1 Gain and L_{opt} as a function of T/W for fixed P_0 and W. $P_0 = 1$ W, $W = 0.1$ μs, and $L = 20$ km.

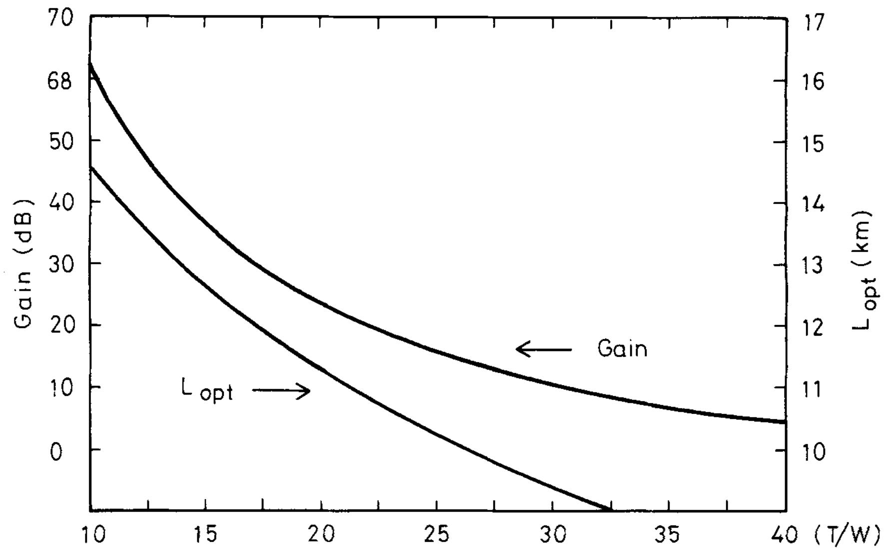

Figure 2 Gain and L_{opt} as a function of T/W for fixed P_L and W. All the parameters are the same as Figure 1.

CONCLUSION

In summary, we have presented the analytical expressions for backward Raman amplification. On the basis of the results, we find that if equal average pump power is used, it is advantageous to use high-power density pulse-pumping sources which can obtain higher gain than CW or low-power density pulse sources. It also shows that there exists an optimum pumping length which results in maximum gain.

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MULTIFUNCTIONAL LED ARRAY-SWITCHING CIRCUITRY

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KEY TERMS

LED array, infrared, array-switching circuit

ABSTRACT

This paper describes a multifunctional IR LED switching circuit that was designed for free optical channel transmission at various wavelengths in an efficient and economical way.

I. INTRODUCTION

The concept of a multifunctional IR transmitting device is shown in Figure 1 in block diagram form. It is composed of a symmetrical arrangement of LEDs of two different wavelengths, some of which form a "diode bridge." Their switching can be multiplexed by using four tri-state [1] semiconductor devices (S_1–S_4). The circuit is highly reliable due to built-in redundancy and can perform several functions which can be broadened and tailored to specific needs by simple programming of a few additional external components. The LEDs can physically be laid out in many ways [2], while maintaining the electrical connections shown in Figure 1.

LEDs a_1–a_6 may radiate at a wavelength, say λ_1, while LEDs b_1–b_6 may radiate at another wavelength, say λ_2. Diode D can be either a common diode or a "pilot source" emitting at a third wavelength, say λ_3, to initiate a synchronization signal at the receiver s or to provide feedback information at the transmitter level.

II. SOME BASIC FUNCTIONS OF THE CIRCUIT

A. Transmission of Single Modulated Wavelength and Pilot Signal. With the tri-state switches S_3 and S_4 set to the