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A SIMPLIFIED PARTIAL POWER MODEL OF SLIGHTLY UNSTABLE FUSED COUPLED FIBERS

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ABSTRACT

Coupled fibers are successfully fabricated by injecting hydrogen flow at 1bar and fused slightly by unstable torch flame in the range of 800-1350°C. Optical parameters may vary significantly over wide range physical properties. Coupling coefficient and refractive index are estimated from the experimental result of the coupling ratio distribution from 1% to 75%. The change of structural and geometrical fiber affects the normalized frequency (V) even for single mode fibers. Coupling ratio as a function of coupling coefficient and separation of fiber axis changes with respect to V at coupling region. V is derived from radius, wavelength and refractive index parameters. Parametric variations are performed on the left and right hand side of the coupling region. At the center of the coupling region V is assumed constant. A partial power is modeled and derived using V, normalized lateral phase constant (u), and normalized lateral attenuation constant, (w) through the second kind of modified Bessel function of the l order, which obeys the normal mode, LP_{01} and normalized propagation constant (b). Total power is maintained constant in order to comply with the energy conservation law. The power is integrated through V, u and w over the pulling length range of 7500-9500μm for 1-D where radial and angle directions are ignored. The core radius of fiber significantly affects V and power partially at coupling region rather than wavelength and refractive index of core and cladding. This model has power phenomena in transmission and reflection for industrial application of coupled fibers.

Keywords: model, fibers, coupling, ratio, coefficient, frequency, power.

INTRODUCTION

The waveguide carrying electric field, a single mode fiber (SMF-28e®) has been successfully coupled by two fibers with the same geometry 1X2 splitting one power source to become two transmission lines as Y junction. The fibers are approximately heated with a slightly unstable torch within a temperature range of 800-1350C. A laser diode source λ =1310nm is used to guide a complete power transfer over a distance of z. The coupling ratio set cannot determine that the cladding diameter is constant even though the LP_{01} diameter position has been achieved. The decrease of the refractive index at the junction fibers is due to effects of structural and geometrical fiber by pulling them at a coupling region, while the 2 cores distance is closer than the radius of those two claddings (Pone 2004). The SMF-28e® core after fusion is reduced from 80.5% to 94% (Saktioto 2007). A half distance of pulling length of fiber coupler increases significantly over the coupling ratio. The coupling length increases over coupling ratio due to the longer time taken at the coupling region by a few milliseconds to attain a complete coupling power.

During fusion, the power transmission and coupling coefficient are fluctuated slightly due to the effects of twisting fibers, fibers heating, and refractive index changes (Saktioto 2007; Senior 1996) which cannot be easily controlled easily. However, experimentally the coupling coefficient is in the range of 0.9-0.6/mm corresponding to refractive index of the core and cladding at values of is n_1 = 1.4640-1.4623 and n_2 = 1.4577 - 1.4556 respectively for coupling ratio of 1 - 75%. The separation of fibers between the two cores is obtained at a mean value of 10-10.86μm (Saktioto 2007). To obtain a higher coupling power, the experimental result should meet the power transmits at the coupling region for a larger coupling length.

A fusion process will change the structures and geometries of coupled fibers at the coupling region. These changes are complicated as the refractive indices and fiber geometries are made uncertain due to the slightly unstable torch flame and coupling ratio effect (Kashima 1995). However, they tend to decrease along the fibers from one edge to the center of the coupling region and again increase to the other. It also occurs to the wave and power propagation partially but total power obeys the energy conservation law (Yariv 2003). The coupling region itself has three regions based on the core and cladding geometry which is situated at the left, center and right. At the center of the coupling region, the main coupling which the power propagation splits from one core to another through the cladding.

Although the coupling ratio research has shown good progress in the experimental and theoretical calculation, coupled waveguide fibers still have reflection and power losses due to effects of fabrication. Coupling fiber fabrications do not only take into account the source and waveguide but also involves some parametric function that emerges along the process when information transfer to fibers occurs (Sharma 1990; Yokohama 1987). This results in a complicated problem, particularly at the junction as the electric field and power are affected by the waveguide, the structure and the geometry of the fiber

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itself. The loss of transmission and coupling power is significant especially in delivering the power ratio.

To investigate the coupling region, the power is simply derived and modeled. The power propagates along SMF-28e® depending on the normalized frequency. The normalized frequency is a function of the core radius, wavelength, and the refractive index of core and cladding. The partial power change and its dependence on normalized frequency parameters are studied. This paper describes power gradient and its integration as computed from coupling coefficient range and coupling region data which is experimentally obtained from the coupling ratio distribution.

PARTIAL POWER GRADIENT MODEL

Wave propagation in cylindrical waveguide for medium is assumed isotropic, linear, non-conducting, non-magnetic but inhomogeneous. The wave equation is as follows:

$$\nabla^2 \mathbf{E} + \nabla\{(1/\varepsilon_r)\ \nabla(\varepsilon_r) . \mathbf{E}\} - \mu_o \varepsilon_o \partial^2 \mathbf{E}/\partial t^2 = 0$$

The wave equation of electric field vector $\mathbf{E}$, where $n=\sqrt{\varepsilon_r}$, is similarly for magnetic field $\mathbf{H}$, where it changes to scalar Ψ as:

$$\nabla^2 \Psi = \varepsilon_o \mu_o\, n^2\, \partial^2 \Psi/\partial t^2$$

Solving this equation for an ideal step-index fiber under the weakly guiding approximation, gives a set of solutions [8],

$$\Psi(r,\varphi,z,t) = R(r)\, e^{il\varphi}\, e^{i(\omega t - \beta z)}$$

$$\text{where } R(r) = \begin{cases} A\, J_l\,(ur/a) & \begin{cases} \cos(l\,\varphi)\ ;\ r<a \\ \sin(l\,\varphi)\ ;\ r<a \end{cases} \\ B\, K_l\,(wr/a) & \begin{cases} \cos(l\,\varphi)\ ;\ r>a \\ \sin(l\,\varphi)\ ;\ r>a \end{cases} \end{cases}$$

A and B are constant, J_l *and* K_l are Bessel and Hankel functions (the second kind of modified Bessel function), where the solution depends upon normalized lateral phase constant (u), and normalized lateral attenuation constant, (w) for modes l (0,1,2,…). The Bessel functions $J_l\ (ur/a)$ are oscillatory in nature, and hence there exists m allowed solutions (corresponding to m roots of J_l) for each value of l. Thus, the propagation phase constant β is characterized by two integers, l and m.

Single mode fiber (SMF) has dominant mode, LP_{01} with normalized frequency, V=2.405. It has two radii with two refractive indices $n_1 \approx n_2$ where n_1 and n_2 are core and cladding respectively, and the radius is the discontinuity at $r = a$. When two coupled fibers are being fused and pulled, the value changes depending on the wavelength source and material of the fibers. At coupling region the changes of some optical parameters are due to the structural and geometrical properties of the fibers. Fiber sizes are decreased and increased on the left and right coupling region. At the center of the coupling region it is assumed to be constant. Consider the pulling length of fibers as follows:

$$P_L = PL_1 + PL_2 + PL_3,$$

Where $PL_1 = PL_3$ and $PL_2 = C_L$ (C_L is coupling length).

Power propagation (P) along coupling region can be reflected and transmitted as a normalized frequency. The total power input and output must however be conservative. Total scalar power for core and cladding power can be defined as follows (Khare 2004):

$$P = P_{core} + P_{cladding}$$

$$P = (constant)\left[\int_{r=0}^{a}\int_{\varphi=0}^{2\pi} |\Psi(r,\varphi)|^2 r\, dr\, d\varphi + \int_{r=a}^{\infty}\int_{\varphi=0}^{2\pi} |\Psi(r,\varphi)|^2 r\, dr\, d\varphi\right]$$

then,

$$P = C\,\pi\, a^2 \left[\left\{1 - \frac{J_{l-1}(u)J_{l+1}(u)}{J_l^2(u)}\right\} + \left\{\frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)} - 1\right\}\right]$$

$$P = C\,\pi\, a^2\, (V^2/u^2)\left[\frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)}\right] \quad (1)$$

Where C is constant of A and B, a is core radius, u is normalized lateral phase constant, w is the normalized lateral attenuation constant, K is the second kind of modified Bessel function of order l. For a k range species of coupling region, total power can be written as a sum of partial power,

$P = \sum_{k=(+,0,-)}^{3} P_k$ the subscript of k is (+), (0) or (-) and

then, the value of $\nabla \sum_{k=(+,0,-)}^{3} P_k$ is a function of $\nabla P = \nabla P\,(a,V,u,w)$, resulting in a set of equations in z direction,

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$$\nabla \sum_{k=(+,0,-)}^{3} P_k = \nabla \{C\pi a^2 (V^2/u^2) [\frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)}]\}$$

$$= \{ C\pi [a^2 V^2 \frac{\partial}{\partial z}(1/u^2) + (a^2/u^2)\frac{\partial}{\partial z}(V^2) + (V^2/u^2)\frac{\partial}{\partial z}(a^2)] \}$$

$$x \{ \frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)} \} + \{C\pi a^2 (V^2/u^2) \frac{\partial}{\partial z} [\frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)}]\} \quad (2)$$

For simplicity, the first, second and third term of the equation (2), respectively is noted as the following:

$$\nabla \sum_{k=(+,0,-)}^{3} P_k = \{[A] \; x \; [B]\} - [C] \quad (3)$$

Firstly, consider $\{[A] \; x \; [B]\}$ as a function of u, V, and a, where

$$\left.\begin{array}{l} u^2 \equiv (k^2 n_1^2 - \beta_{lm}^2)a^2 \\ w^2 \equiv (\beta_{lm}^2 - k^2 n_2^2)a^2; \quad \beta_1 = kn_1 \; ; \beta_2 = kn_2 \\ V = (u^2 + w^2)^{1/2} = (2\pi a/\lambda)\,(n_1^2 - n_2^2)^{1/2} \end{array}\right\} \quad (4)$$

Where l and m are the number of modes, β is the propagation constant and k is the wave number. The left hand side of Equation (4) have parametric values dependent on the values of $u = u(a,k,n_1,\beta_{lm})$, $w = w(a,k,n_2,\beta_{lm})$, and $V = V(a,n_1,n_2,\lambda)$ [8]. The value of β_{lm} is calculated from the normalized propagation constant b,
which is equal to $(\beta^2_{lm} - \beta_2)/(\beta_1 - \beta_2)$. Since w is a part of K function, then it can be derived by the K function itself. Evaluating these functions separately over z direction we find,

$$\left.\begin{array}{l} \nabla u = [(ak^2 n_1^2 da/dz + ka^2 n_1^2 dk/dz + n_1 k^2 a^2 \, dn_1/dz) - (a\beta_{lm}^2 da/dz + \beta_{lm} \, a^2 d\beta_{lm}/dz)] \,/\, (u) \\ \nabla \beta_{lm} = [\beta_2(d\beta_2/dz) + b_{lm}(\beta_1 \, d\beta_1/dz - \beta_2 \, d\beta_2/dz)] \,/\, (\beta_{lm}) \\ \nabla V = 2\{(\pi/\lambda)(n_1^2 - n_2^2)^{1/2} da/dz + \pi a(n_1^2 - n_2^2)^{1/2}[d(1/\lambda)/dz] \, d\lambda/dz \\ \quad + (2\pi a/\lambda) \, [½ \, (n_1^2 - n_2^2)^{-1/2}] \, (n_1 dn_1/dz - n_2 \, dn_2/dz)\} \end{array}\right\} \quad (5)$$

Where db_{lm}/dz is expected to be zero, and thus can be ignored. The first and second terms of equation (3) can be rewritten by combining equation (5) as follows:

$$\{[A] \; x \; [B]\} = \{ 2C\pi [- u^{-3} a^2 V^2 \frac{\partial u}{\partial z} + V (a^2/u^2) \frac{\partial V}{\partial z} + a (V^2/u^2) \frac{\partial a}{\partial z}] \} \; x \{ \frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)} \} \quad (6)$$

The K function can be derived by the first order resulting in,

$$[C] = C\pi a^2 (V^2/u^2)$$

$$x \{ \frac{[(K_{l-1}(w))' K_{l+1}(w) + K_{l-1}(w)(K_{l+1}(w))'][K_l(w)] - [2(K_l(w))' K_{l-1}(w)K_{l+1}(w)]}{(K_l^3(w))} \} \quad (7)$$

Equations (6) and (7) are then combined to have a solution of equation (3). In order to obtain a complete solution, the second kind of modified Bessel function of order l is substituted by a recurrence relation for a given function as,

$$K_n'(x) = \frac{n}{x} K_n(x) - K_{n+1}(x)$$

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Then it is finally given by,

$$\nabla \sum_{k=(+,0,-)}^{3} P_k = \overbrace{\left[2C\pi \{-u^{-3} a^2 V^2 \frac{\partial u}{\partial z} + V(a^2/u^2)\frac{\partial V}{\partial z} + a(V^2/u^2)\frac{\partial a}{\partial z}\}\right.}^{(I)}$$

$$x\{ \overbrace{\frac{K_{l-1}(w)K_{l+1}(w)}{K_l^2(w)}}^{(II)} \}] - \overbrace{[\, C\pi a^2 (V^2/u^2)\; x}^{(III)}$$

$$\{ [\overbrace{\{\frac{l-1}{w}K_{l-1}(w) - K_{(l-1)+1}(w)\}}^{(IV)}\overbrace{K_{l+1}(w)}^{(V)} + K_{l-1}(w)\overbrace{\{\frac{l+1}{w}K_{l+1}(w) - K_{(l+1)+1}(w)\}}^{(VI)}]\overbrace{K_l(w)}^{(VII)}$$

$$-\overbrace{[2\{\frac{l}{w}K_l(w) - K_{l+1}(w)\}K_{l-1}(w)K_{l+1}(w)]}^{(VIII)} \;\}\,] \qquad (8)$$

Equation (8) can be computed by setting a number of known parameters and evaluated within the boundary conditions of coupling region as defined by equation (3). Since the total power obeys the energy conservation law, then $\nabla P = 0$. It can then be applied for each k region as:

$$\nabla \sum_{k=(+,0,-)}^{3} P_k = \nabla P|_{+} + \nabla P|_{0} + \nabla P|_{-} = 0$$

The value of $\nabla P|_{+}$ corresponds to positive gradient where the radius of fibers is decreased and negative gradient when the radius of fibers is increased at $\nabla P|_{-}$. At PL_2, it is assumed that $\nabla P|_0 \approx 0$. For a simplified partial power model, the fibers are imposed by setting a temperature and the change of fiber properties as inhomogeneous. At PL_1 the value of a linearly changes as same as n_1 and n_2 towards the temperature. Meanwhile, the wavelength linearly depends upon n_1 and n_2. These parameter changes are the same at PL_3 but with the opposite sign. Therefore, the total power is constant, but the partial power is not zero. It can be written as:

$\nabla P|_{+} \neq 0$, $\nabla P|_{-} \neq 0$, but for $\nabla P|_0 \approx 0$

For the range of coupling region where P will be calculated, and to correct $\frac{dP}{dz}$ for effect of change in fibers geometry, Equation (8) can be derived and fixed to be a constant value.
Suppose total and derivation of P is rewritten as:

$$P = \sum_{k=(+,0,-)}^{3} P_k$$

$$\frac{dP}{dz} = \nabla \sum_{k=(+,0,-)}^{3} P_k \qquad (9)$$

Where the total ∇P is not constant. Hence,

$$\frac{1}{\nabla P}\frac{dP}{dz} = \frac{1}{z}$$

where z is the power direction. Multiplying both sides with P_k and $\frac{1}{\nabla P}$ for normalization of ∇P, equation (9) becomes,

$$\frac{P_k}{\nabla P}\frac{dP}{dz} = P_k \left[\sum_{k=(+,0,-)}^{3} \frac{1}{\nabla P}\right]\frac{d}{dz}(P_+ + P_o + P_-) \qquad (10)$$

In order to keep total ∇P constant, we combine the two terms of equation (9) and (10) for P_k obtaining

$$\left(\frac{dP_k}{dz}\right)_{correction} = \left(\frac{dP}{dz}\right) - \frac{P_k}{\nabla P}\frac{dP}{dz} \qquad (11)$$

This formula expresses that during the power propagation at the coupling region, total ∇P is constant even though P_k changes. For illustration, this model can then be depicted in Figure-1.

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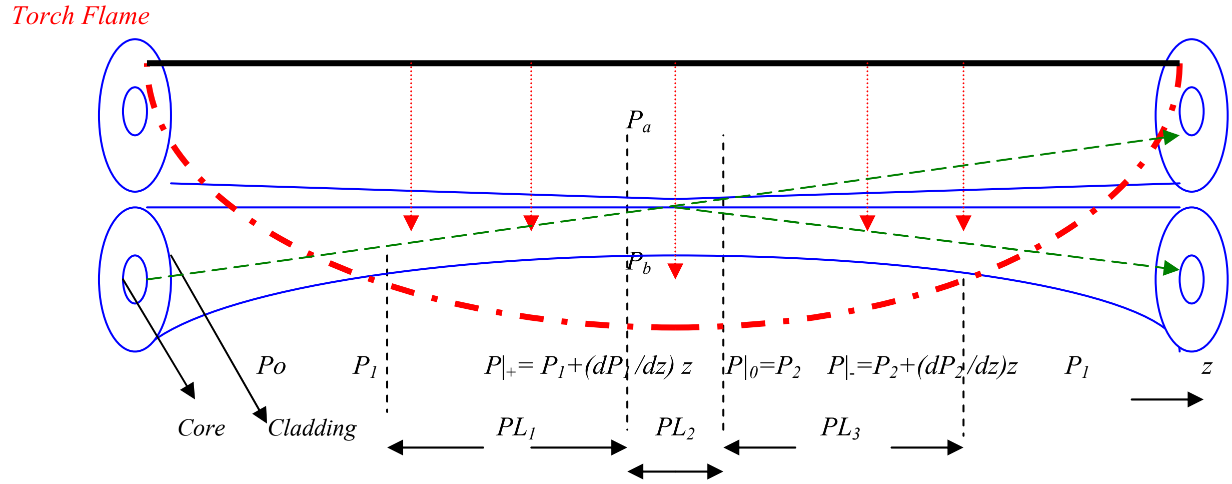

Figure-1. SMF-28e® coupler fiber is heated by H_2 gas at the temperature of 800-1350C. The core and cladding reduce 75-90% in size after fusion. Total pulling of fibers to the left and right side is in the range of 7500-9500µm with a velocity of ≈ 100µm/s. Pulling is stopped subject to the coupling ratio achieving a pre-set value.

INTEGRATION OF POWER AND DISCUSSIONS

The values of P partially change at the coupling region are integrated over z direction of core radius and a half pulling length. It is run in Ode45 Matlab platform with a set of input data for refractive index of core and cladding, wave length and initial P. For the given values of equation (4), it shows that at PL_1, the result is as follows:

$$\left.\begin{aligned}
&\nabla(a)|_{+} = 1044.3864 \text{ to } 796.8127 \times 10^{-6},\\
&\nabla(\lambda)|_{+n1} = -0.0006542 \text{ to } -0.0010101 \times 10^{-9},\\
&\nabla(\lambda)|_{+n2} = -0.0008376 \text{ to } -0.0012823 \times 10^{-9},\\
&\nabla(n_1)|_{+} = 1.05 \text{ to } 1.65 \times 10^{-6},\\
&\nabla(n_2)|_{+} = 1.35 \text{ to } 2.05 \times 10^{-6},\\
&da/dz = 7.9681 \text{ to } 9.0039 \times 10^{-4},\ dk/dz = 2.3952 \text{ to } 3.6983,\\
&dn_1/dz = 1.05 \text{ to } 1.65 \times 10^{-6},\quad dn_2/dz = 1.35 \text{ to } 2.05 \times 10^{-6}\\
&d\beta_1/dz = 8.5516 \text{ to } 13.3419,\quad d\beta_2/dz = 9.9779 \text{ to } 15.2409,\\
&d\beta_{lm}/dz = 9.2064 \text{ to } 14.2137,\\
&\nabla u = 322.5195 \text{ to } 364.4422,\\
&\nabla V = 475.5291 \text{ to } 537.3407
\end{aligned}\right\} \qquad (12)$$

These parametric values exist as a result of the coupling ratio in the range of 1 to 75%. It has a function of coupling coefficient and produces the parametric values gradients existing in that number range. The value of $\lambda_o/\lambda = n$ moves to decrease along PL_1 until it meets the coupling length and inversely increases along PL_3. The equation (12) is similar to PL_3 but the gradient is in the opposite sign.

The graph of ∇P at PL_1, as calculated from Equation (10) is the power gradient at the first and end of the coupling region as depicted in Figure-2.

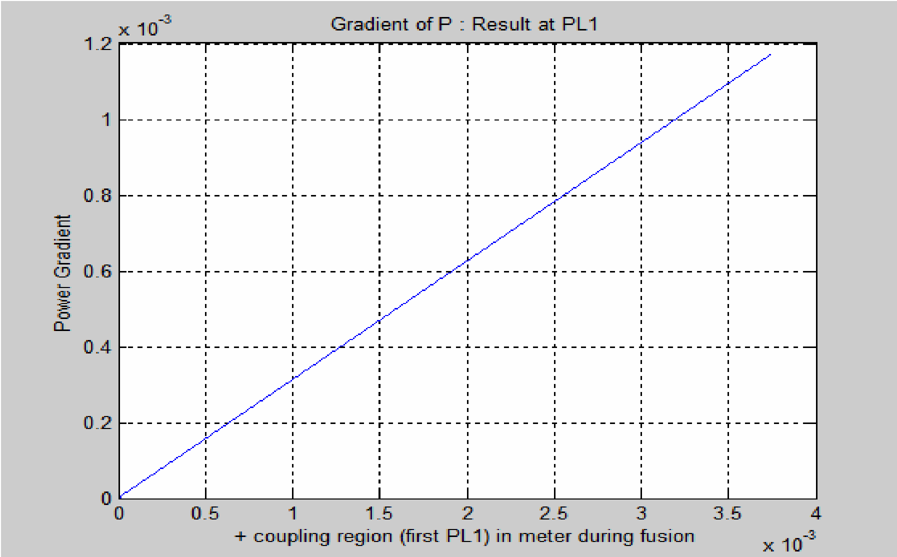

Figure-2. ∇P along coupling region; ∇P =1.18 at first of PL_1 and 1.26 at end of PL_1 at coupling region z = $3.75\text{x}10^{-3}$m.

Comparing the two curves, it shows that the change of partial P is less than that shown at the end of PL_1. It shows that end of PL_1 has decreased smoothly due to the fact of pulling length and heating of fibers at end of PL_1. It also meant that the higher gradient to reach coupling length has resulted in the more reflection of power to the source fiber and crosstalk fiber due to the refractive indices gradient and more loss of power from the core to the cladding and to the edge cladding due to the radius gradient. This result has the same values for PL_3 but in the negative gradient.

If we assume that partial ∇P is not linear and exponentially decreasing or increasing. If it is affected by the function factor $P = P\,(1+e^{-\alpha})$ then the radius geometry is not proportional to the speed of pulling length and if by the function factor $P = P\,(1-e^{-\alpha})$ then it means that the fibers are not precisely heated at the center of fibers and the gradient of refractive indices will be close to factor 10^{-3}. However, these reasons are negligible, since the mechanical process of the fabrication is fixed and the radius change is much more significant than the other parameters.

Table-1. Calculation of partial ∇P in each term of equation (8).

No.	Calculation Result	Term
1	(0.2857 – 0.0546i) to (0.3229 – 0.006171i)	I
2	(0.9899 + 0.5456i)	II
3	($-7.3511 \times 10^{-4} + 1.45057 \times 10^{-4}$i)	III
4	(0.1154 – 0.1875i)	IV,VII
5	(-0.3056-0.2007i)	V,VII
6	(0.0177 + 0.6021i)	VI
7	(0.1154 – 0.1876i)	V,VI,VII
8	(-0.2169 + 0.4334i)	VIII
9	(0.3126 + 0.10181i) to (0.3533 + 0.1150i)	I and II
10	($-1.847\,\text{x}10^{-5} - 4.0113 \times 10^{-5}$i)	III to VIII
11	(0.3126 + 0.1018i) to (0.3533 + 0.1150i)	I to VIII

Based on Table-1, the results are significantly affected by multiplication of term I and II by a factor of 10^{-1} rather than multiplication of term III until term VIII. Before being derived, term II is comparable towards term I in contributing the power. In fact, the order of l deserves to the balancing of term I, but term III is too high a factor by the order of 10^{-4}, then the effect of power gradient is seemingly contributed by term I. The main influence of term III is the value of core radius by factor of a^2 which similarly occurs in term I. However, since term I is a summation operation then it disappears. Therefore, partial ∇P is reduced by the value of a and ∇P is otherwise increased by K function of l order in term II. In other words, in summation operation, K function is dominant but in reduced operation, the value of a becomes significant. The partial power gradient at PL_1 and PL_3 results in parametric changes to reduce or to add power significantly along coupling region. This calculation can also be seen in Figure-3. As shown by the straight lines in Figure-3, when power gradient is integrated, it describes the first PL_1 as higher than that of end PL_1. The left coupling region is set at z = 0 and let the power curves move from P input to the output at 3.75 x 10^{-3}mm. This phenomena expresses the change of each parameter of P is set nearly linear although the actual changes are not obvious. One of the parametric values of P is evaluated in linear assumption that gives a significant dependence in changing to both gradient and integral of P is radius of core by order 10^{-3}. Refractive indices and wavelength do not necessarily have linear impact since refractive indices and wavelength difference are by the order of 10^{-6} and 10^{-9} respectively. Therefore the linear effect is maintained to retain the mode at LP_{01}. The P input value changes at coupling length position from 1 mW to 0.31mW for one core and 0.62mW for two cores. Implicitly it shows that the partial power transmission will reduce along the coupling region as a result of refractive indices, core geometry and separation of fiber axis between the cores. This partial power results seem to be very significant, but it actually decreases or increases partially from one core source radiates to its cladding and also to another core and cladding when coupled.

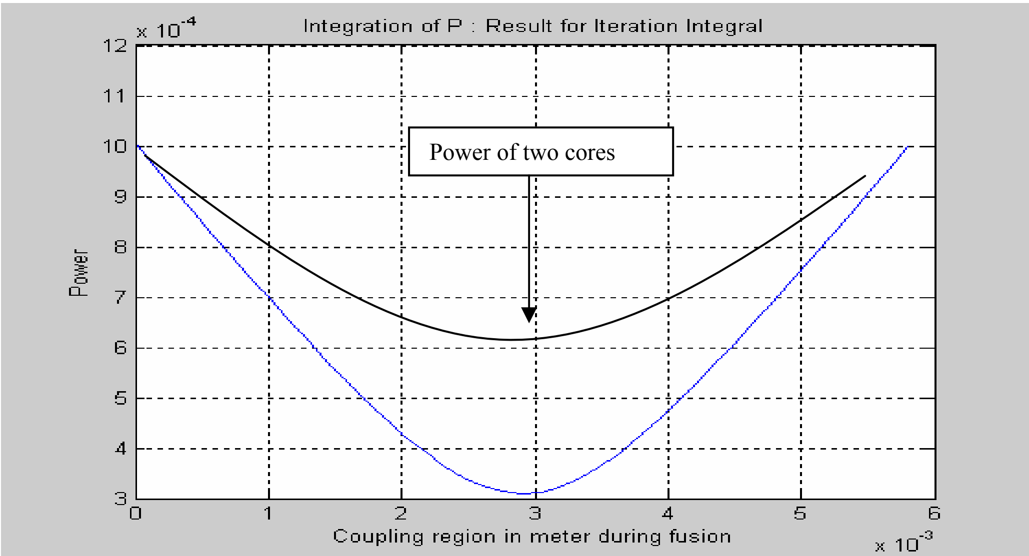

Figure-3(a)

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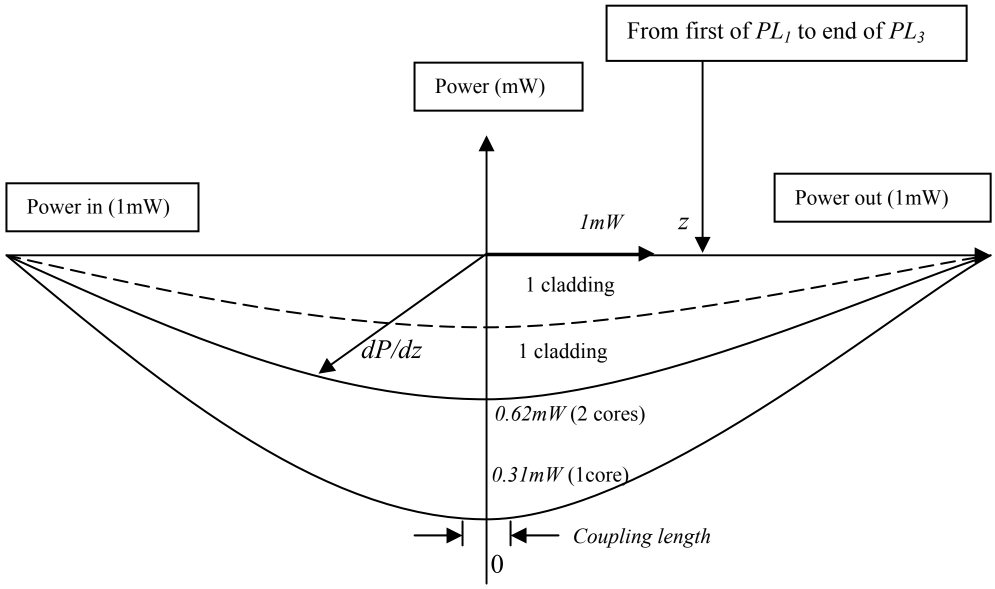

Figure-3(b)

Figure-3. *P* integration over coupling region (power source of one core); 3(a) and Illustration of power propagation; 3(b).

Table-2 describes the details of parametric value changes along the coupling region. A validation of code results is maintained by the initial and final *P*, while at the coupling region (excluding coupling length) it is assumed to change linearly.

Table-2. Power parameters of coupled SMF-28e®.

Parameter	∇ at first of PL_1	∇ at end of PL_1	∇ at PL_2	∇ at first of PL_3	∇ at end of PL_3
z position	0 ⟶ 3.75x10^{-3}	⟶	5.42x10^{-3}	⟶ 7.5x10^{-3}mm	⟶
λ	0 to 4.5x10^{-9} (+)	0 to 7x10^{-9} (+)	0	0 to -7x10^{-9} (-)	0 to -4.5x10^{-9} (-)
a	0 to 1.5 (+)	0 to 2 (+)	0	0 to -2 (-)	0 to -1.5 (-)
n_1,n_2	0 to -2.55x10^{-7} (-)	0 to -3.48x10^{-7}(-)	0	0 to 3.48x10^{-7}(+)	0 to 2.55x10^{-7}(+)
β_{lm}	0 to 0.035 (+)	0 to 0.054 (+)	0	0 to 0.054 (-)	0 to 0.035 (-)
u	0 to 1.2 (+)	0 to 1.38 (+)	0	0 to 1.38 (-)	0 to 1.2 (-)
V	0 to 1.8 (+)	0 to 2 (+)	0	0 to -2 (-)	0 to -1.8 (-)

Initial SMF-28e® $V= V_1$ = 2.4506; n_1=1.4677 and n_2=1.4624; and a = 4.1 x 10^{-6}m
The initial core and cladding diameter are respectively 8.2µm and 125µm
C = 6.4032x10^6 – 1.2245x10^{6}i, *P* =1mW; $P_{cladding}/P_{total}$ = 0.1702, P_{core}/P_{total} = 0.8298,
After Fusion: $V= V_2$ = 0.9761- 0.3353; n_1=1.4623-1.4640; n_2=1.4556-1.4577; and a = 0.5-1.5 x 10^{-6}m
(V, V_1 and V_2 values are calculated from refractive indices known. The symbol of (+) and (-) indicates positive and negative gradient respectively and deal with along each z direction 0 to 3.75 x 10^{-3}mm).

CONCLUSIONS

Coupling ratio range of 1 to 75% with coupling coefficient at 0.6-0.9/mm has successfully been developed for partial power gradient and its integration along the coupling region. Normalized frequency and power gradient give significant parametric changes over power transmission into fiber at coupling region from the power source of one core. The core radius is much more affected to ∇P rather than the refractive indices and wavelength although they change linearly.

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