Jurnal
Teknologi

Full Paper

Z-TRANSFORM METHOD FOR OPTIMIZATION OF ADD-DROP CONFIGURATION SYSTEM

Article history
Received
10 October 2014
Received in revised form
10 December 2014
Accepted
13 January 2015

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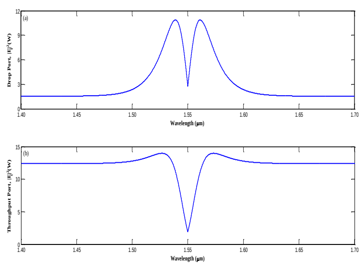
Graphical abstract



Abstract

This paper presents the new approaches of optimization the add-drop configuration system by using Z-transform method. Dark soliton was chosen as the input signal and Gaussian beam was chosen as the control signal for the model proposed. The incident light was said to achieve the maximum resonance with the ring resonator when the phase shift, $\phi = 2\pi m$. The derivation, analyzation, and optimization of the system are typically very important especially for the communication technology.

Keywords: Optical solitons, Z-transform method, dark-bright soliton, Gaussian beam

Abstrak

Penerbitan ini mempersembahkan cara terbaru untuk mengoptimumkan sistem penambah-lepasan menggunakan kaedah Z-ubahan. Soliton gelap dipilih sebagai signal masukan dan pancaran Gaussian dipilih sebagai signal pengawal bagi sistem dicadangkan. Cahaya pancaran dikatakan mencapai resonans maksimum dengan pengalun cincin apabila fasa ubahan, $\phi = 2\pi m$. Pembuktian, penganalisisan, dan pengoptimuman sistem ini sangat penting terutamanya dalam bidang komunikasi.

Kata kunci: Soliton optik, Kaedah Z-ubahan, soliton gelap-cerah, pancaran Gaussian

1.0 INTRODUCTION

Add-drop configuration system consists of unidirectional coupling between a ring resonator and nonlinear fibre waveguides [1] as depicted in Figure 1. Four channels of the ring resonator system are marked as input, add, throughput, and drop ports, depicted as E_{in}, E_{add}, E_t, and E_d respectively. When an input electric field is coupled into the ring waveguide through an external bus waveguide, a positive feedback is induced. The field inside the ring resonator is said to starts build-up [2]. Tuned soliton pulses are obtained using add-drop and PANDA multiplexers.

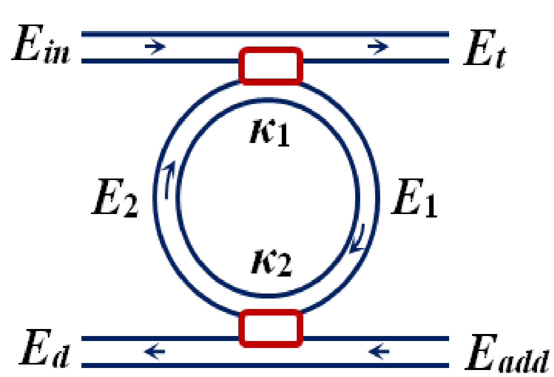


Figure 1 Add-drop configuration system

2.0 ANALYZATION AND OPTIMIZATION OF ADD-DROP SYSTEM

Input dark soliton was launched into the system through the input port and controlled by Gaussian beam at the add port respectively. The power intensities coupled into the system is t times the input power for through-path transmission and κ times the input power for cross-path transmission [3]. t and κ are the self-coupling coefficient and cross-coupling coefficient of the waveguide respectively.

t and κ are related as [4]:

$$|\kappa^2| + |t^2| = 1 \tag{1}$$

The transmission for one complete roundtrip is represented as:

$$exp\left(\frac{-\alpha L}{2} - jk_n L\right) \tag{2}$$

The Z-transform parameter is given as [5]:

$$z^{-1} = exp^{-jk_n L} \tag{3}$$

where $k_n = \frac{2\pi}{\lambda} n_{eff}$ is the propagation constant, λ is the wavelength, and n_{eff} is the effective refractive index of the waveguide.

The transmission optical field E_t at throughput port is given as [6]:

$$E_t = \left[t_1 + (-\kappa_1)^2 (t_2)(z^{-1})(a) \cdot \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] . E_{in} \tag{4}$$

By using Taylor's expansion series, Equation (4) can be simplified as:

$$E_t = \left[\frac{t_1 - t_2 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} \tag{5}$$

The transmission power, P_t is then given as [7]:

$$P_t = E_t \cdot E_t^* = \frac{t_1^2 + a^2 t_2^2 - a t_1 t_2 \left(e^{-jk_n L} + e^{jk_n L}\right)}{1 + a^2 t_1^2 t_2^2 - a t_1 t_2 \left(e^{-jk_n L} + e^{jk_n L}\right)} \cdot E_{in}^2 \tag{6}$$

By using $e^{jx} = \cos(x) + j\sin(x)$ and $e^{-jx} = \cos(x) - j\sin(x)$, Equation (6) becomes:

$$P_t = \frac{t_1^2 + a^2 t_2^2 - 2 a t_1 t_2 \cos(k_n L)}{1 + a^2 t_1^2 t_2^2 - 2 a t_1 t_2 \cos(k_n L)} \cdot E_{in}^2 \tag{7}$$

The transmission optical field, E_d at drop port, from input E_{in} is given as [8]:

$$E_d = \left[-\kappa_1 \kappa_2 \sqrt{a}\sqrt{z^{-1}} \cdot \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots + (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] \cdot E_{in} = \left[\frac{-\kappa_1 \kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} \tag{8}$$

The transmission power, P_d is given as [9]:

$$P_d = E_d \cdot E_d^* = \frac{a(1 - t_1^2)(1 - t_2^2)}{1 + a^2 t_1^2 t_2^2 - 2 a t_1 t_2 \cos(k_n L)} \cdot E_{in}^2 \tag{9}$$

The transmission optical field, E_t at throughput port, from input E_{add} is given as [10]:

$$E_t = \left[-\kappa_1 \kappa_2 \sqrt{a}\sqrt{z^{-1}} \cdot \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots + (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] . E_{add} = \left[\frac{-\kappa_1 \kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \tag{10}$$

The transmission power, P_t is given as [11]:

$$P_t = E_t \cdot E_t^* = \frac{a(1 - t_1^2)(1 - t_2^2)}{1 + a^2 t_1^2 t_2^2 - 2 a t_1 t_2 \cos(k_n L)} \cdot E_{add}^2 \tag{11}$$

The transmission optical field E_d at drop port from input E_{add} is given as [10]:

$$E_d = \left[t_2 + (-\kappa_2)^2 (t_1)(z^{-1})(a) \cdot \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots + (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] \cdot E_{add} = \left[\frac{t_2 - t_1 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \tag{12}$$

The transmission power, P_d is given as [11]:

$$P_d = E_d \cdot E_d^* = \frac{t_2^2 + a^2 t_1^2 - 2 a t_1 t_2 \cos(k_n L)}{1 + a^2 t_1^2 t_2^2 - 2 a t_1 t_2 \cos(k_n L)} \cdot E_{add}^2 \tag{13}$$

The scattering matrix method is used to obtain the total optical transmission field at throughput and drop ports, which is given as [12]:

$$\begin{bmatrix} E_t \\ E_d \end{bmatrix} = S_R \begin{bmatrix} E_{in} \\ E_{add} \end{bmatrix} \quad (14)$$

S_R is given as:

$$S_R = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} = \begin{bmatrix} \left[\frac{t_1 - t_2 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] & \left[\frac{-\kappa_1 \kappa_2 2\sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \\ \left[\frac{-\kappa_1 \kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] & \left[\frac{t_2 - t_1 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \end{bmatrix} \quad (15)$$

Hence,

$$\begin{bmatrix} E_t \\ E_d \end{bmatrix} = \begin{bmatrix} \left[\frac{t_1 - t_2 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] & \left[\frac{-\kappa_1 \kappa_2 2\sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \\ \left[\frac{-\kappa_1 \kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] & \left[\frac{t_2 - t_1 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \end{bmatrix} \begin{bmatrix} E_{in} \\ E_{add} \end{bmatrix} \quad (16)$$

By solving the matrix, Equations (10) and (12) becomes:

$$E_t = E_{throughput} = \left[\frac{t_1 - t_2 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{i1} + \left[\frac{-\kappa_1 \kappa_2 2\sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (17)$$

and

$$E_d = E_{drop} = \left[\frac{-\kappa_1 \kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{i1} + \left[\frac{t_2 - t_1 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (18)$$

The interaction between the input optical field, E_{in} and control signal, E_{add} occurs inside the ring resonator waveguide. The circulated optical fields, E_1 and E_2 inside the system can be written as follows [13].

Circulated field E_{11}, from input field E_{in} is given as:

$$E_{11} = \left[-\kappa_1 \sqrt{a z^{-1}} \cdot \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots + (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] \cdot E_{in} = \left[\frac{-\kappa_1 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} \quad (19)$$

Similarly, circulated field E_{12} from input field E_{add} can be expressed as:

$$E_{12} = \left[-t_1 \kappa_2 a z^{-1} \cdot \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots + (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] \cdot E_{add} = \left[\frac{-t_1 \kappa_2 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (20)$$

Circulated field E_{21} from input field E_{in} can be expressed as:

$$E_{21} = \left[-t_2 \kappa_1 a z^{-1} \cdot \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots + (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] \cdot E_{in} = \left[\frac{-t_2 \kappa_1 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} \quad (21)$$

Similarly, circulated field E_{22} from input field E_{add} is given as:

$$E_{22} = \left[-\kappa_2 \sqrt{a z^{-1}} \begin{Bmatrix} 1 + (t_1 t_2 a z^{-1}) + (t_1 t_2 a z^{-1})^2 \\ + \cdots + (t_1 t_2 a z^{-1})^n \end{Bmatrix}\right] \cdot E_{add} = \left[\frac{-\kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (22)$$

Hence, the transmission fields at E_1 and E_2 are given as:

$$E_1 = \left[\frac{-\kappa_1 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} + \left[\frac{-t_1 \kappa_2 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (23)$$

and

$$E_2 = \left[\frac{-t_2 \kappa_1 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} + \left[\frac{-\kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (24)$$

Finally, the output fields at throughput and drop ports are given as:

$$E_t = \left[\frac{t_1 - t_2 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} + \left[\frac{-\kappa_1 \kappa_2 2\sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (25)$$

and

$$E_d = \left[\frac{-\kappa_1 \kappa_2 \sqrt{a z^{-1}}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{in} + \left[\frac{t_2 - t_1 a z^{-1}}{1 - t_1 t_2 a z^{-1}}\right] \cdot E_{add} \quad (26)$$

3.0 RESULTS AND DISCUSSION

Add-drop system is very useful for filtering and cancelling the chaotic signals, which is important indeed for the communication and security link technologies. Dark soliton pulse with 3.50 W input power is launched into the system through the input port and Gaussian beam with 1.22 W input power is injected through the add port. In operation, a 34 µm ring resonator radius is used for the proposed system. By using InGaAsP/InP fibre waveguide [14], the refractive index of the fibre, n_o = 3.34. The waveguide wave coefficient, α and the intensity insertion loss coefficient, γ of the coupler are α = 0.05 dB km^{-1} and γ = 0.1 respectively. Two fibre couplers connected with both bus waveguides, marked with κ_1 and κ_2 respectively as depicted in the schematic diagram shown in Figure 1. The coupling coefficients, κ_1 and κ_2 values are set at κ_1 = 0.55 and κ_2 = 0.35 respectively. The results for output fields at throughput and drop ports, E_t and E_d of the system were examined.

The interaction between dark soliton and Gaussian beam within the system are shown in Figure 2 where Figure 2(a) is the output signal at drop port, E_d and Figure 2(b) is the signal generated at the throughput port, E_t of the system. The highest output power generated were 10.798 and 13.944 W for E_d and E_t ports respectively. The set-up in Figure 1 is then modified by adding a PANDA ring to the model designed. Due to the dynamical behaviour of the PANDA system, the signal flow through the right and left sides of the nanorings results the large amplification of the travelling optical signals. At the circulating points E_1 and E_2, the signals are tuned in the ring resonator due to resonance [15]. The circulating process within the ring results the high output signals of the system. The signals filtering and cancelling process of the add-drop system results the single signal as the outputs as depicted in Figure 3. Those input and control signals were continuous to propagate into the system and caused the optical collisions between both signals within ring waveguides. Figure 3 shows the output signals generated at throughput port where Figure 3(a) shows the output signal generated without filtering process and Figure 3(b) shows the signal generated after add-drop filtering process take placed. It can see that the maximum power generated increased up to 18.834 W instead of 13.944 W without the existence of the PANDA system. This is due to the intensity build-up factor within both right and left nanorings [16].

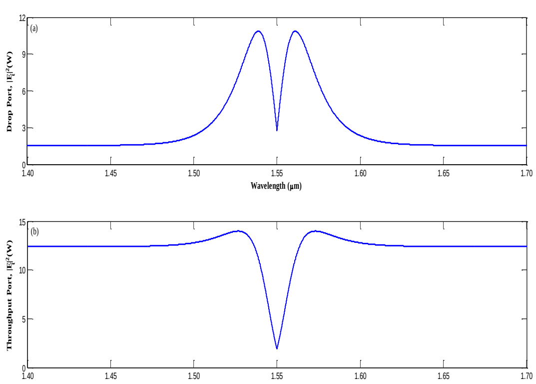


Figure 2 Output signal of the add-drop system at the (a) drop port (b) throughput port

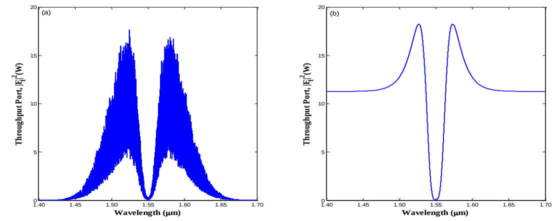


Figure 3 Generated signals at throughput port of the system where (a) without filtering process (b) after filtering process

As discussed, the system consists of an input and an add ports, where these two parameters influence the performance of the system at the circulating fields as well as output fields characteristics. The input power is one of very important parameter which will give big effects towards the performance of the system. The input power values are varied from 5 to 50 W respectively. The power value of the control signal is fixed at E_{add} = 2 W. It is shown that the values of output power increases with increase of the input power, E_{in} as in Figure 4. From the graph plotted, it can be seen that the output power of the system increases exponentially with the increase in the values of input power, E_{in}. This is significantly related from the theoretical calculation where:

$$E = A\, e^{i(kz-\omega t)} \tag{27}$$

$$E^2 = A^2\, e^{2i(kz-\omega t)} \tag{28}$$

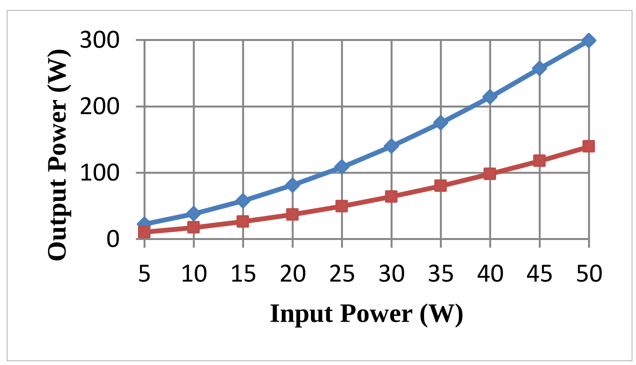


Figure 4 Relationship between input and output power at throughput and drop ports of the system

4.0 CONCLUSION

The development and analyzation of the add-drop configuration system using Z-transform method have been done. The meaningful of the optical solitons channel trapping toward the communication technology and the used of the PANDA system collaborated with add-drop configuration system have been investigated thoroughly. It is proved that the value of input signal of the system giving a big effect towards the system performance.

Acknowledgement

The authors like to acknowledge Laser Center, Ibnu Sina Institute for Scientific & Industrial Research, Universiti Teknologi Malaysia for supporting this research.

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