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# BER OF ANNULAR BEAMS IN WEAK OCEANIC TURBULENCE

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**ABSTRACT:** Based on Rytov method, on-axis scintillation index of laser communication link in a weak oceanic medium is formulated for collimated annular beam. Employing these obtained scintillation values, average bit error rate (<BER>) is evaluated where the intensity has log-normal distribution. Scintillation indices of collimated annular beams are found for fixed primary source size $\alpha_{s_1}$ , varying annular beam thickness, propagation distance $L$ , source size $\alpha_s$, the rate of dissipation of the mean squared temperature $\chi_T$ , non-dimensional parameter representing the relative strength of temperature and salinity fluctuation $w$. <BER> versus the source size and the average signal to noise <SNR> found for the collimated annular beams are exhibited for various rate of dissipation of turbulent kinetic energy per unit mass of fluid $\varepsilon$ and source sizes $\alpha_s$. At the stated link lengths, as secondary source size of annular beam equals to zero, that is, for Gaussian beam, <BER> will offer more advantages.

***Key Words :*** *Oceanic turbulence, Ocean optics, Optical communication, Scintillation, BER*

## Halkasal Hüzmenin Zayıf Okyanussal Türbülansta Bit Hata Oranı

**ÖZ:** Rytov yöntemine dayalı olarak zayıf bir okyanussal ortamdaki lazer iletişim bağlantısının eksen üzerine ıpıldama indeksi, paralelleştirilmiş halka hüzmesi için formüle edilmiştir. Elde edilen bu değerler kullanılarak, ortalama bit hata oranı (<BER>), log-normal dağılımlı olarak değerlendirilmiştir. Paralelleştirilmiş halkalı hüzmelerin ıpldama indeksleri; sabit birincil kaynak boyutu $\alpha_{s_1}$ , değişen dairesel hüzme kalınlığı, yayılma mesafesi $L$ , kaynak boyutu $\alpha_s$, ortalama karesel sıcaklığın dağılma oranı $\chi_T$ , sıcaklık ve tuzluluk dalgalanmasının göreli kuvvetini temsil eden boyutsuz parametresi $w$ için bulunur. Paralelleştirilmiş halka hüzmesi için kayanak büyüklüğü ve ortalama sinyal gürültü oranı (<SNR>)' na göre <BER>, birim kütle akışkanı ve kaynak boyutları için türbülans kinetik enerjinin çeşitli dağılım oranı için sergilenmektedir. Belirtilen iletişim bağlantısında, halkasal hüzmelerin ikincil kaynak boyutu sıfıra eşit olduğunda, yani Gaussian hüzmesi olduğunda, <BER> daha fazla avantaj sağlayacaktır.
***Anahtar Kelimeler :*** *Okyanussal türbülans, Okyanus optiği, Optiksel haberleşme, ıpıldama, BER*

## INTRODUCTION

Optical communications in underwater channels have fluctuations in the intensity measured by the scintillation index. This affects the behaviour of the <BER> which is one of the most important performance criteria in the link design. Some studies concerning the scintillation index of laser beams

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show how much the fluctuations in the intensity, measured by the scintillation index, impress the optical communication in not only weak turbulence but also in strong turbulence. Also the types of beam model effect the scintillations, hence the <BER> at the receiver (Tatarski, 1961; Ishimaru, 1978; Andrews *et al.*, 2001; Andrews *et al.*, 2005; Arpalı and Baykal, 2009; Arpalı *et al.,2008;* Vetelino *et al.*, 2007; Sandalidis *et al.*, 2008; Tyson *et al.*, 2005; Namazi *et al.*, 2007; Gerçekcioglu *et al.*, 2010; Gerçekcioglu and Baykal, 2013; Gerçekcioglu and Baykal, 2013; Gerçekcioglu *et al.*, 2010; Gerçekcioglu and Baykal, 2011; Gerçekcioglu *et al.*, 2010). Studies involving scintillation index of annular beams have revealed important results at the atmospheric channel (Gerçekcioglu *et al.*, 2010; Gerçekcioglu and Baykal., 2013; Gerçekcioglu and Baykal, 2013; Gerçekcioglu *et al.*, 2010; Gerçekcioglu and Baykal, 2011; Gerçekcioglu *et al.*, 2010).

The propagation of various kind of laser beams used in wireless optical links in underwater channels will cause intensity fluctuations, also affect the performance of optical communication link (Kumar *et al.*, 2011; Lu *et al.*, 2006; Korotkova *et al.*, 2012; Baykal, 2015; Yousefi *et al.*, 2015; Yi *et al.*, 2015; Gökçe *et al.*, 2016; Baykal, 2016; Cheng *et al.*, 2016; Peng *et al.*, 2017; Nikishov and Nikishov, 2000; Gerçekcioglu, 2014; Ata and Baykal, 2014). Especially, the scintillation indices of optical plane and spherical and Gaussian beams propagating in underwater turbulent media are researched by using the Rytov method (Gerçekcioglu, 2014; Ata and Baykal, 2014).

In this study, thanks to utilizing the spatial power spectrum of the refractive index of atmospheric media and developed on-axis scintillations in the weak atmospheric optical horizontal links, with the spatial power spectrum of the refractive index of homogeneous and isotropic oceanic water, collimated annular beams propagating in underwater turbulent media are analyzed and the scintillations and <BER> are evaluated in horizontal oceanic optics links by using the Rytov method. Scintillation index of collimated annular beams at changing features for propagation distance and source size is shown. Furthermore, scintillation index and <BER> versus <SNR> are found by using the log-normal distributed intensity for the collimated annular beams versus the for non-dimensional ratio of the relative strength of temperature and salinity fluctuations $w$, various source sizes $\alpha_s$, the rate of dissipation of the mean squared temperature $\chi_T$ and the rate of dissipation of turbulent kinetic energy per unit mass of fluid $\varepsilon$ .

**FORMULATION**

The on-axis scintillation index $m^2$ of annular beams in ocean turbulence (Gercekcioğlu and Baykal, 2011) with the spatial power spectrum of the refractive index of homogeneous and isotropic oceanic water represented by $\Phi_n(\kappa)$ for $\kappa > 0$ is represented as (Lu *et al.*, 2006; Nikishov and Nikishov, 2000),

$$m^2 = 4\pi \,\mathrm{Re}\left\{ \int_0^L d\eta \int_0^\infty \kappa d\kappa \int_0^{2\pi} d\phi \left[ T_{A_1}(\eta,\kappa,\phi) + T_{A_2}(\eta,\kappa,\phi) \right] \Phi_n(\kappa) \right\} \tag{1}$$

where Re(.) is to the real part of the argument, $\eta$ is the variable showing the length along the propagation axis, $L$ is the propagation distance of the link, $\kappa \exp(i\phi)$ is the two dimensional spatial frequency in polar coordinates, $\kappa$ is the magnitude, $\Gamma(.)$ is the Gamma function,

$$\Phi_n(\kappa)=(4\pi)^{-1}\beta\chi_n\varepsilon^{-1/3}\kappa^{-11/3}\left[1+Q(\kappa\eta_s)^{2/3}\right]\left[w^2\theta+1-w(1+\theta)\right]^{-1}$$
$$\times\left(w^2\theta\exp\left\{-\beta Pr_T^{-1}\left[\frac{2}{3}(\kappa\eta_s)^{4/3}+Q(\kappa\eta_s)^2\right]\right\}+\exp\left\{-\beta Pr_S^{-1}\left[\frac{2}{3}(\kappa\eta_s)^{4/3}+Q(\kappa\eta_s)^2\right]\right\}\right.$$
$$\left.-w(1+\theta)\exp\left\{-0.5\beta\frac{(Pr_T+Pr_S)}{Pr_T Pr_S}\left[\frac{2}{3}(\kappa\eta_s)^{4/3}+Q(\kappa\eta_s)^2\right]\right\}\right) \tag{2}$$

where, the rate of the dissipation of the mean squared refractive index fluctuation is $\chi_n=A^2\chi_T(w-1)^2/w^2$, $\chi_T$ is the rate of dissipation of the mean squared temperature taking values for smaller $\varepsilon$ close in the range from $10^{-2}$ $K^2/s$ to $10^{-10}$ $K^2/s$, $\beta$ is the Obukhov–Corrsin constant whose value is taken as 0.72, $\varepsilon$ is the rate of dissipation of turbulent kinetic energy per unit mass of fluid, the non-dimensional constant $Q$ is a free parameter to be determined by comparison with experiment where its value is taken as 2.35, and $\eta_s=(\nu^3/\varepsilon)^{1/4}$ is the Kolmogorov microscale, $\nu$ being the kinematic viscosity, $w$ is non-dimensional representing the relative strength of temperature and salinity fluctuations, which in the ocean waters can vary between -5 and 0, $\theta=1$ when the quantity of eddy thermal diffusivity equals to the quantity of diffusion of the salt, $\mathrm{Pr}_T$ and $\mathrm{Pr}_S$ represent the Prandtl numbers for temperature and salinity respectively, where $\mathrm{Pr}_T$=7 and $\mathrm{Pr}_S$=700, and the refractive index is expressed as a function of temperature and salinity fluctuation, $A=2.6\times10^{-4}$ l/deg is a constant.

The expressions in the integrand of Eq. (1) are

$$T_{A_1}(\eta,\kappa,\phi)=-k^2D(L)^{-2}A^2(1+i\alpha L)^{-2}\exp\left[-i(L-\eta)k^{-1}(1+i\alpha\eta)(1+i\alpha L)^{-1}\kappa^2\right] \tag{3}$$

$$T_{A_2}(\eta,\kappa,\phi)=k^2\left|D(L)\right|^{-2}AA^*(1+i\alpha L)^{-1}(1-i\alpha^*L)^{-1}$$
$$\times\exp\left\{-0.5i(L-\eta)k^{-1}\left[(1+i\alpha\eta)(1+i\alpha L)^{-1}-(1-i\alpha^*\eta)(1-i\alpha^*L)^{-1}\right]\kappa^2\right\} \tag{4}$$

where $D(L)=A(1+i\alpha L)^{-1}$ and the annular beam incident field at the source plane is given as $u_s(\mathbf{s})=u_s(s_x,s_y)=\sum_{l=1}^{2}A_l\exp\left[-0.5k\alpha_l s_x^2-0.5k\alpha_l s_y^2\right]$, these examples of annular beam expressed by $\mathbf{s}=(s_x,s_y)$ is the transverse coordinate at the source plane, $s_x,s_y$ representing the *x* and *y* components, $A_\ell$ is in general the complex amplitude of the source field, $A_1=-A_2=1$, * is the complex conjugate, $i=(-1)^{0.5}$, $k=2\pi/\lambda$ is the wave number, $\lambda$ is the wavelength, $\alpha_1=1/(k\alpha_{s1}^2)+j/F_1$, $\alpha_{s1}$ and $F_1$ are the Gaussian source size and focusing parameter of the symmetrical primary beam. Likewise, $\alpha_2=1/(k\alpha_{s2}^2)+j/F_2$, $\alpha_{s2}$ and $F_2$ are the Gaussian source size and focusing parameter of the symmetrical secondary beam, thickness is defined as difference between primary and secondary source (Gerçekcioğlu *et al.*, 2010).

Substituting Eqs. (3), (4) and the spatial power spectrum of refractive index fluctuation given in Eq. (2) into Eq. (1), performing the integration over $\kappa$ and $\psi$, the on-axis scintillation index of annular beams in weak oceanic turbulence is found which is expressed as,

$$m^2 = 8\pi^2 k^2 \operatorname{Re}\left\{ \left|D(L)\right|^{-2} AA^* \left(1+i\alpha L\right)^{-1} \left(1-i\alpha^* L\right)^{-1} \int_0^L d\eta \left(E_{A_1} + F_{B_1}\right) \right. \\ \left. - D(L)^{-2} A^2 \left(1+i\alpha L\right)^{-2} \int_0^L d\eta \left(E_{A_2} + F_{B_2}\right) \right\} \tag{5}$$

where

$$E_{A_1} = (8\pi)^{-1} K_{k_1} \left\{ w^2\theta \sum_{k=0}^{\infty} \frac{(-1)^k A_{T_1}^k \Gamma(2k/3-5/6)}{k!} \left[ A_{T_2} + \frac{i(L-\eta)}{2k} \left( \frac{1+i\alpha\eta}{1+i\alpha L} - \frac{1-i\alpha^*\eta}{1-i\alpha^* L} \right) \right]^{-2k/3+5/6} \right. \\ - w(1+\theta) \sum_{k=0}^{\infty} \frac{(-1)^k A_{TS_1}^k \Gamma(2k/3-5/6)}{k!} \left[ A_{TS_2} + \frac{i(L-\eta)}{2k} \left( \frac{1+i\alpha\eta}{1+i\alpha L} - \frac{1-i\alpha^*\eta}{1-i\alpha^* L} \right) \right]^{-2k/3+5/6} \\ \left. + \sum_{k=0}^{\infty} \frac{(-1)^k A_{S_1}^k \Gamma(2k/3-5/6)}{k!} \left[ A_{S_2} + \frac{i(L-\eta)}{2k} \left( \frac{1+i\alpha\eta}{1+i\alpha L} - \frac{1-i\alpha^*\eta}{1-i\alpha^* L} \right) \right]^{-2k/3+5/6} \right\} \tag{6}$$

$$F_{B_1} = (8\pi)^{-1} K_{k_2} \left\{ w^2\theta \sum_{k=0}^{\infty} \frac{(-1)^k A_{T_1}^k \Gamma(2k/3-1/2)}{k!} \left[ A_{T_2} + \frac{i(L-\eta)}{2k} \left( \frac{1+i\alpha\eta}{1+i\alpha L} - \frac{1-i\alpha^*\eta}{1-i\alpha^* L} \right) \right]^{-2k/3+1/2} \right. \\ - w(1+\theta) \sum_{k=0}^{\infty} \frac{(-1)^k A_{TS_1}^k \Gamma(2k/3-1/2)}{k!} \left[ A_{TS_2} + \frac{i(L-\eta)}{2k} \left( \frac{1+i\alpha\eta}{1+i\alpha L} - \frac{1-i\alpha^*\eta}{1-i\alpha^* L} \right) \right]^{-2k/3+1/2} \\ \left. + \sum_{k=0}^{\infty} \frac{(-1)^k A_{S_1}^k \Gamma(2k/3-1/2)}{k!} \left[ A_{S_2} + \frac{i(L-\eta)}{2k} \left( \frac{1+i\alpha\eta}{1+i\alpha L} - \frac{1-i\alpha^*\eta}{1-i\alpha^* L} \right) \right]^{-2k/3+1/2} \right\} \tag{7}$$

$$E_{A_2} = (8\pi)^{-1} K_{k_1} \left\{ w^2\theta \sum_{k=0}^{\infty} \frac{(-1)^k A_{T_1}^k \Gamma(2k/3-5/6)}{k!} \left[ A_{T_2} + \frac{i(L-\eta)}{k} \frac{1+i\alpha\eta}{1+i\alpha L} \right]^{-2k/3+5/6} \right. \\ + \sum_{k=0}^{\infty} \frac{(-1)^k \Gamma(2k/3-5/6)}{k!} A_{S_1}^k \left[ A_{S_2} + \frac{i(L-\eta)}{k} \frac{1+i\alpha\eta}{1+i\alpha L} \right]^{-2k/3+5/6} \\ \left. - w(1+\theta) \sum_{k=0}^{\infty} \frac{(-1)^k A_{TS_1}^k \Gamma(2k/3-5/6)}{k!} \left[ A_{TS_2} + \frac{i(L-\eta)}{k} \frac{1+i\alpha\eta}{1+i\alpha L} \right]^{-2k/3+5/6} \right\} \tag{8}$$

$$F_{B_2}=\left(8\pi\right)^{-1}K_{k_2}\left\{w^2\theta\sum_{k=0}^{\infty}\frac{\left(-1\right)^k}{k!}A_{T_1}^{k}\Gamma\left(2k/3-1/2\right)\left[A_{T_2}+\frac{i\left(L-\eta\right)}{k}\frac{1+i\alpha\eta}{1+i\alpha L}\right]^{-2k/3+1/2}\right.$$
$$+\sum_{k=0}^{\infty}\frac{\left(-1\right)^k A_{S_1}^{k}\Gamma\left(2k/3-1/2\right)}{k!}\left[A_{S_2}+\frac{i\left(L-\eta\right)}{k}\frac{1+i\alpha\eta}{1+i\alpha L}\right]^{-2k/3+1/2}$$
$$\left.-w\left(1+\theta\right)\sum_{k=0}^{\infty}\frac{\left(-1\right)^k A_{TS_1}^{k}\Gamma\left(2k/3-1/2\right)}{k!}\left[A_{TS_2}+\frac{i\left(L-\eta\right)}{k}\frac{1+i\alpha\eta}{1+i\alpha L}\right]^{-2k/3+1/2}\right\}, \tag{9}$$

$K_{k_1}=\beta\chi_n\varepsilon^{-1/3}\left[w^2\theta+1-w\left(1+\theta\right)\right]^{-1}$, $K_{k_2}=\beta\chi_n\varepsilon^{-1/3}Q\eta_s^{2/3}\left[w^2\theta+1-w\left(1+\theta\right)\right]^{-1}$, ! denotes the factorial, $A_{S_1}=\frac{2}{3}\eta_s^{4/3}\beta P_{r_S}^{-1}$, $A_{S_2}=\beta P_{r_S}^{-1}Q\eta_s^2$, $A_{T_1}=\frac{2}{3}\eta_s^{4/3}\beta P_{r_T}^{-1}$, $A_{T_2}=\beta P_{r_T}^{-1}Q\eta_s^2$, $A_{TS_1}=\frac{1}{3}\eta_s^{4/3}\beta\left(P_{r_T}+P_{r_S}\right)P_{r_T}^{-1}P_{r_S}^{-1}$, $A_{TS_2}=\frac{1}{2}Q\eta_s^2\beta\left(P_{r_T}+P_{r_S}\right)P_{r_T}^{-1}P_{r_S}^{-1}$.

The <BER> is given by Eq. (3) of [4] as,

$$<\mathrm{BER}>=0.5\int_0^{\infty}p_I(u)erfc\left(<\mathrm{SNR}>2^{-3/2}u\right)du \tag{10}$$

where $erfc(.)$ is the complementary error function, $p_I(u)$ is identified in weak oceanic turbulence as the probability density function of the intensity with $u>0$ as [4],

$$p_I(u)=\frac{1}{m\sqrt{2\pi}u}\exp\left\{-0.5m^{-2}\left[\ln\left(u\right)+0.5m^2\right]^2\right\}. \tag{11}$$

For the collimated annular beams at the origin of the receiver in a weakly turbulent ocean., the <BER> is found by using $m^2$ given in Eq. (5) inserted into $p_I(u)$ given in Eq. (11) which in turn is substituted into Eq. (10).

**RESULTS AND DISCUSSIONS**

In this section, the results are obtained by utilizing the derived formulations in section 2 which are valid in oceanic weak turbulence. As taken in my article published in 2014, it is noted that $\lambda=1.55\ \mu\mathrm{m}$ and $\chi_t=10^{-8}\ \mathrm{K}^2s^{-1}$ are chosen. While Figs.1, 2, 3, 4 and 5 indicate the scintillation indices versus the propagation distance $L$, source size $\alpha_s$, rate of dissipation of the mean squared temperature $\chi_T$ and the ratio of temperature and salinity fluctuations $w$, respectively, Figs. 6, 7 and 8 indicate the variations of <BER> versus the primary source size $\alpha_{s_1}$ at various thickness, versus <SNR> for fixed primary source size $\alpha_{s_1}=1$ cm and $\alpha_{s_1}=2$ cm , respectively.

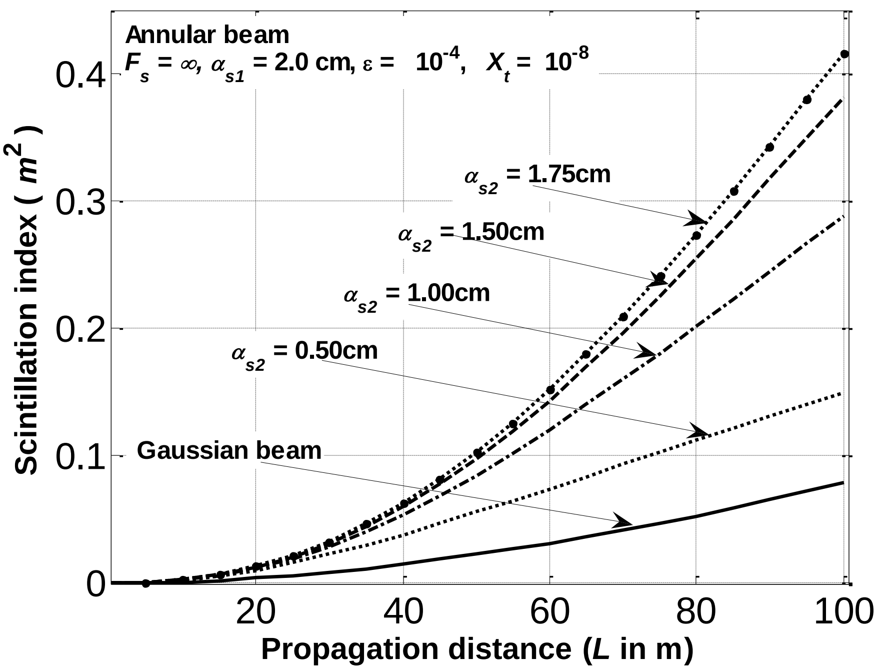


**Figure 1.** Scintillation index versus propagation distance $L$ for collimated annular beams at fixed primary source size ($\alpha_{s1} = 1$ cm) and various thickness.

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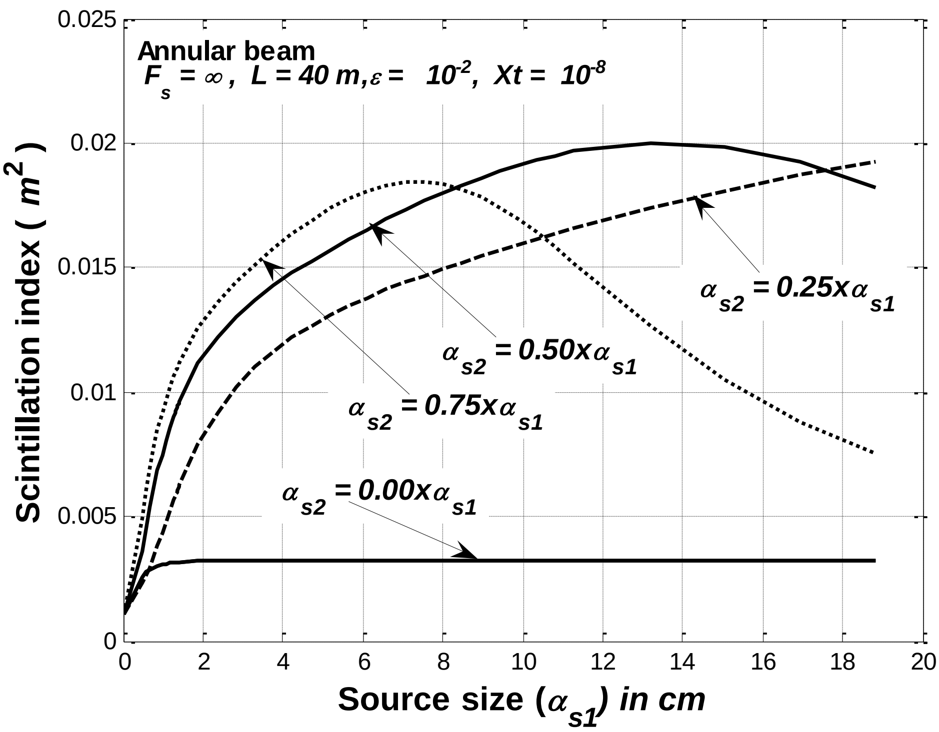


**Figure 2.** Scintillation index versus primary source size $\alpha_{s1}$ for collimated annular beams at various thickness.

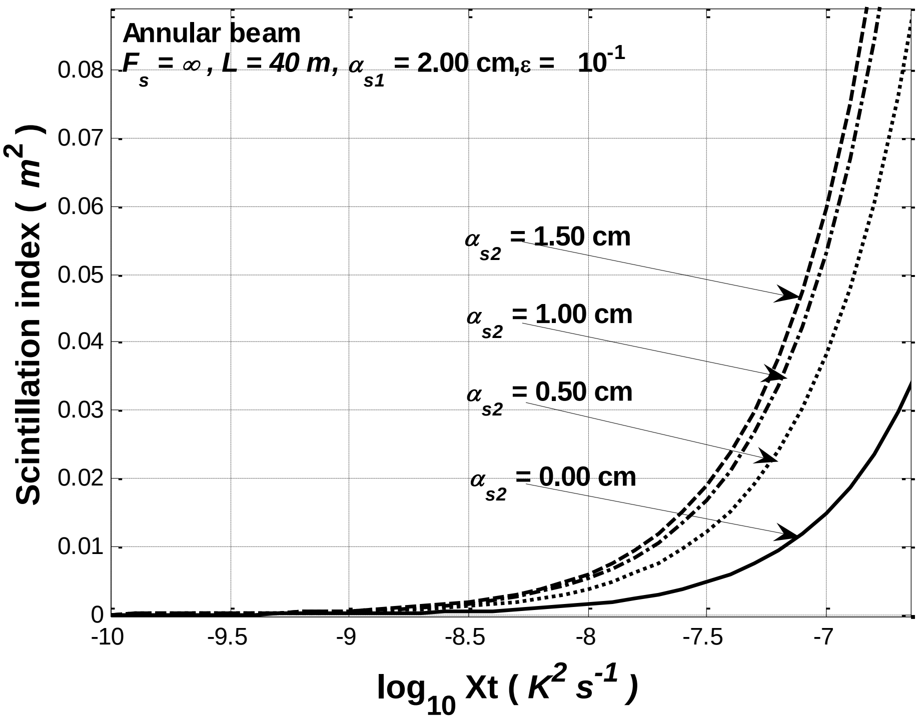


**Figure 3.** Scintillation index versus the rate of dissipation of the mean squared temperature $\chi_T$ for collimated annular beams at fixed primary source size ( $\alpha_{s1} = 2$ cm ) and various thickness.

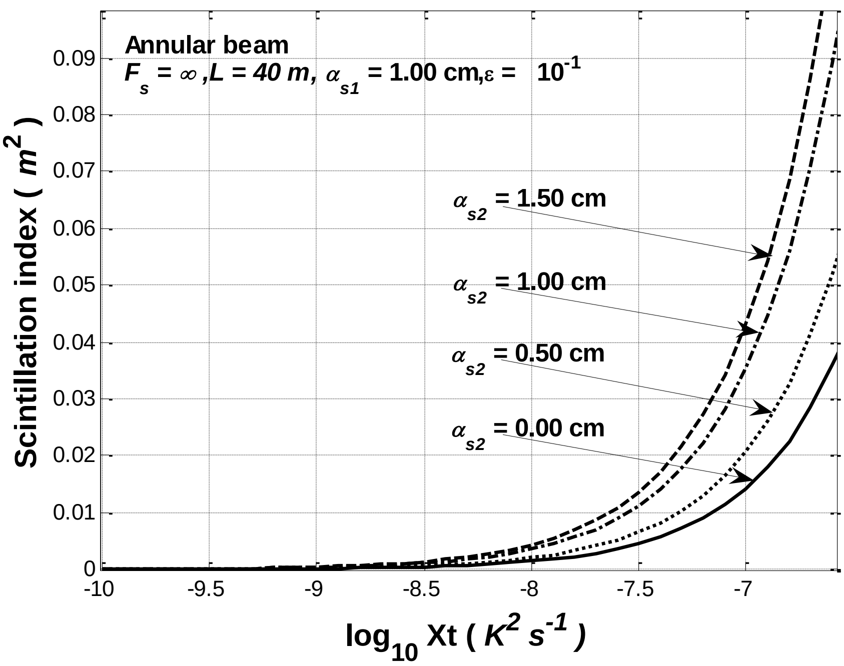


**Figure 4.** Scintillation index versus the rate of dissipation of the mean squared temperature $\chi_T$ for collimated annular beams at fixed primary source size ( $\alpha_{s1} = 1$ cm ) and various thickness.

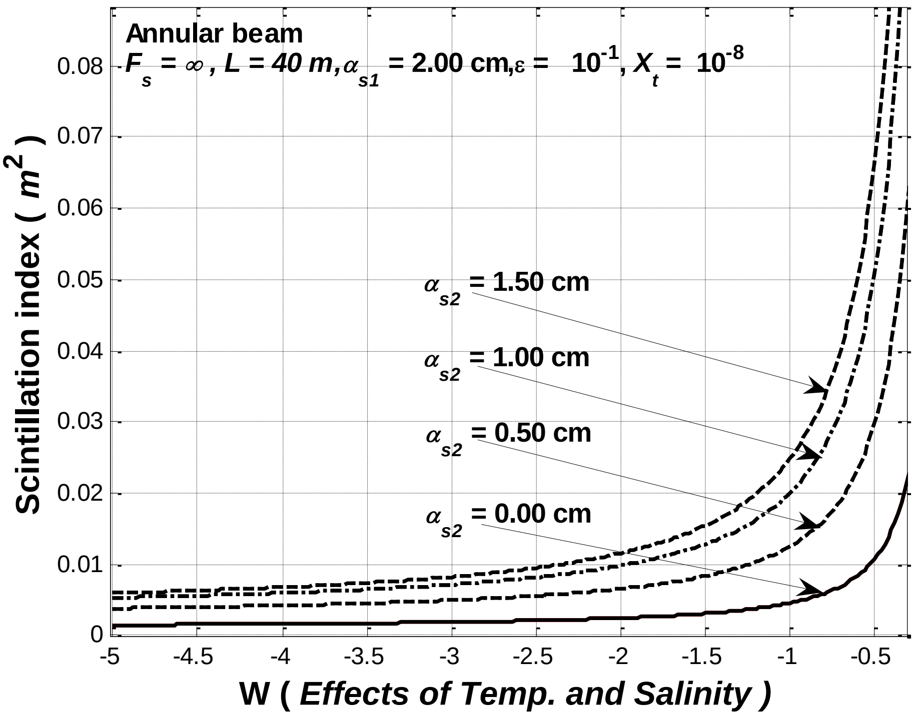


**Figure 5.** Scintillation index versus effects of temperature and salinity fluctuations $w$ for collimated annular beams at fixed primary source size ( $\alpha_{s1} = 2$ cm ) and various thickness.

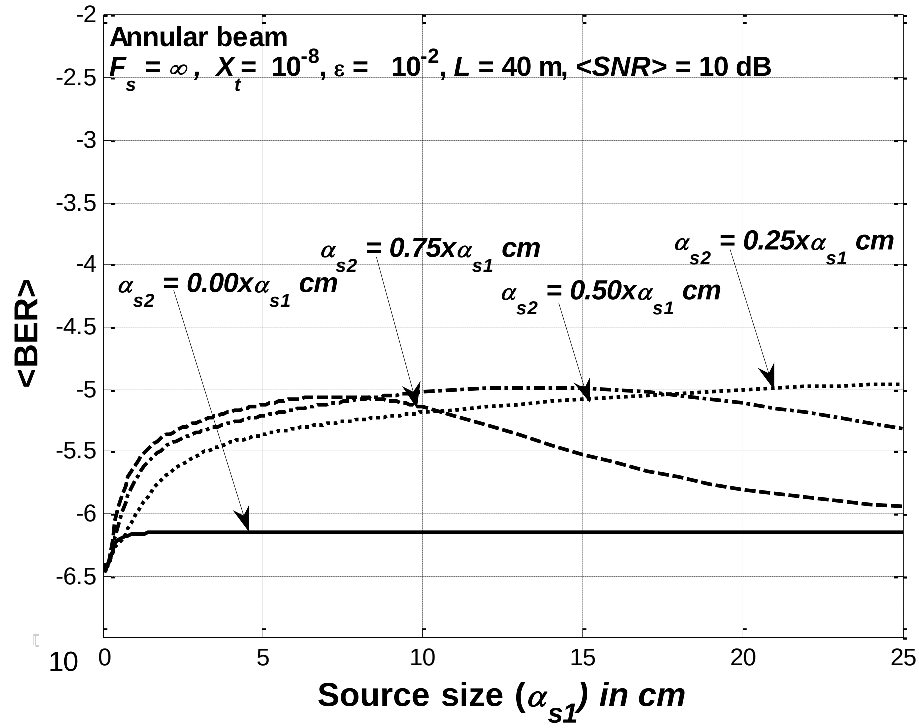


**Figure 6.** <*BER*> versus scintillation index versus primary source size $\alpha_{s1}$ for collimated annular beams at various thickness.

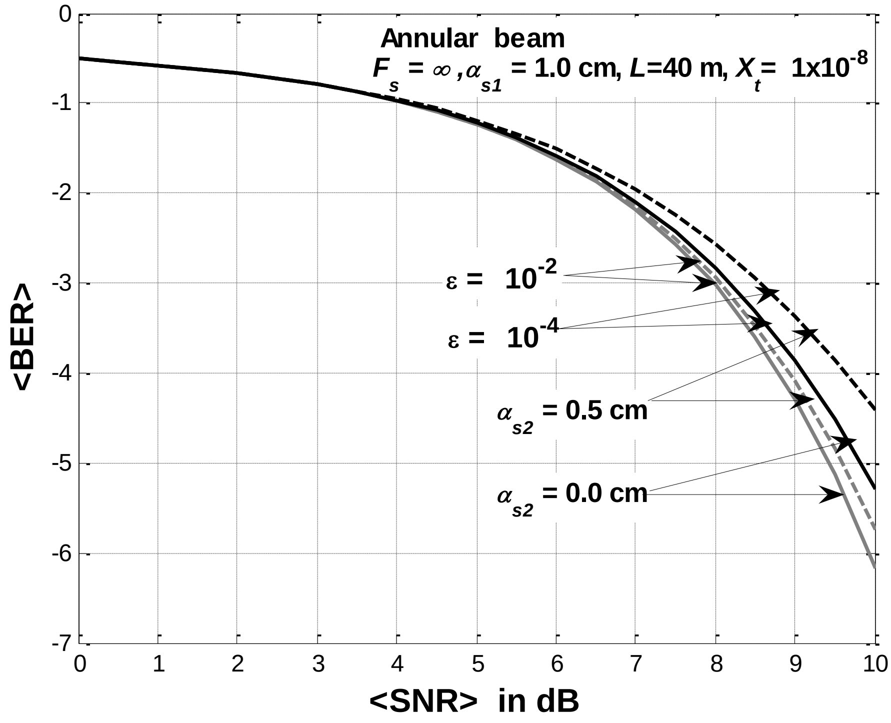


**Figure 7.** <*BER*> versus <*SNR*> for collimated annular beams at fixed primary source size ( $\alpha_{s1} = 1$ cm ), various thickness, and various rate of dissipation of turbulent kinetic energy per unit mass of fluid $\varepsilon$ .

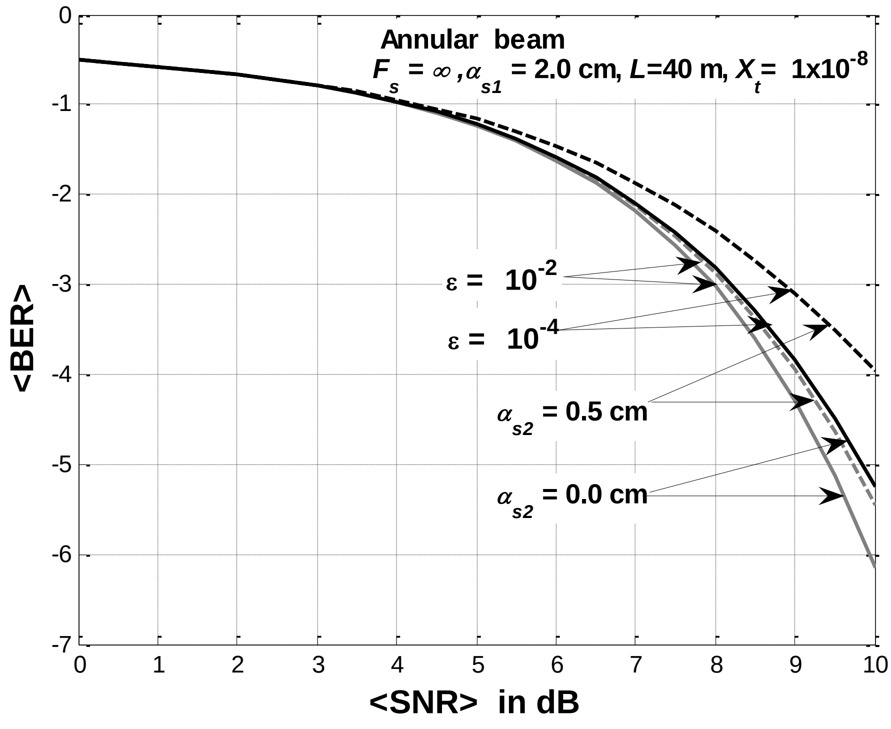


**Figure 8.** <*BER*> versus <*SNR*> for collimated annular beams at fixed primary source size ( $\alpha_{s1} = 2$ cm ), various thickness, and various rate of dissipation of turbulent kinetic energy per unit mass of fluid $\varepsilon$ .

Scintillation index versus propagation distance $L$ for collimated annular beams at $\alpha_{s_1} = 2$ cm, $\chi_t = 10^{-8}$ $K^2 s^{-1}$, $\varepsilon = 10^{-4}$ and various thickness is depicted in Fig.1. As thickness increases, scintillation indices decreases until $\alpha_{s_2}$ equals to zero, i.e, Gaussian beam case. In Fig. 2, scintillation index versus the primary source size $\alpha_{s_1}$ for collimated annular beams at various thickness is drawn for propagation distance $L = 40$ m, $\chi_t = 10^{-8}$ $K^2 s^{-1}$ and $\varepsilon = 10^{-2}$ and is seen that the lowest scintillation indices are at $\alpha_{s_2} = 0$ cm. Fig. 3 and 4 show the scintillation index versus the rate of dissipation of the mean squared temperature $\chi_T$ for collimated annular beams at fixed primary source sizes of $\alpha_{s_1} = 2$ cm and $\alpha_{s_1} = 1$ cm, respectively. Figs. 3 and 4 are drawn at various thickness at the propagation distance $L = 40$ m, $\chi_t = 10^{-8}$ $K^2 s^{-1}$ and $\varepsilon = 10^{-1}$. As the thickness decreases, scintillation indices increase. When Figs.3 and 4 are compared in terms of the scintillation indices at two different source size, smaller source size value has better scintillation indices values.

Scintillation indices are plotted in Fig. 5 versus the ratio of temperature and salinity fluctuations, $w$ for collimated annular beams at $\alpha_{s1} = 2$ cm for fixed primary source size and various thicknesses. The propagation distance is $L = 40$ m, $\chi_t = 10^{-8}$ $K^2 s^{-1}$ and $\varepsilon = 10^{-1}$. Increasing values w cause a rise in scintillations. In Fig. 6, <BER> is depicted versus the primary source size $\alpha_{s1}$ at various thickness values at propagation distance $L = 40$ m, $\chi_t = 10^{-8}$ $K^2 s^{-1}$, $\varepsilon = 10^{-2}$ and <SNR>=10 dB. <BER> is found to have much smaller values when annular beam approaches the Gaussian beam. Figs. 7 and 8 indicate <BER> versus <SNR> for various thickness and $\varepsilon$ values for fixed primary source sizes of $\alpha_{s_1} = 1$ cm and $\alpha_{s_1} = 2$ cm, respectively. For the Gaussian beam, <BER> is found not to change at various $\varepsilon$. However, for the annular beam, small source size yields much lower <BER>. It is also observed that when $\varepsilon$ is larger,<BER> increases.

**CONCLUSION**

In this study, based on the temperature and salinity spatial power spectrum of underwater fluctuations, on-axis scintillation index of annular beam is derived analytically for horizontal optics communication links in a weak oceanic turbulence by utilizing Rytov solution, and <BER> with log-normal intensity distribution is examined. The results of the on-axis scintillation index of annular beam for horizontal optics communication link in weak oceanic turbulence are found to be similar to the previously obtained results for horizontal optics communication links in weak atmospheric turbulence. Our results show that as compared to collimated annular beam, annular beam yields much bigger scintillations at short distances, unlike long distances as in other articles (Namazi *et al.*, 2007; Gerçekcioglu *et al.*, 2010; Gerçekcioglu and Baykal, 2013; Gerçekcioglu and Baykal, 2013; Gerçekcioglu *et al.*, 2010; Gerçekcioglu and Baykal, 2011). Propagation distance is taken shorter than the distances in atmospheric links because strong oceanic turbulence can occur at short distances (Lu *et al.*, 2006). As the annular beam thickness decreases, the scintillation index, and naturally <BER> as well increase. Gaussian beams are found to be favorable when compared to annular beams at the stated distances.

For collimated annular beam in a weak oceanic medium, the figure, including scintillation indices versus propagation distance, shows that as secondary source size increases, scintillation index increases at constant, primary source size, rate of dissipation of turbulent kinetic energy per unit mass of fluid, and rate of dissipation of the mean squared temperature. Again, at constant, stated propagation distance, rate of dissipation of turbulent kinetic energy per unit mass of fluid, and rate of dissipation of the mean squared temperature, when scintillation index and <BER> at fixed <SNR> versus source size is depicted, as secondary source size increases in proportional to the primary source size, scintillation index grows up. But, thinner annular beam has more advantages after a certain value without zero secondary source size. Just as the growth in the rate of dissipation of the mean squared temperature increases scintillation index at fixed, the stated propagation distance, primary source size, and the rate of dissipation of turbulent kinetic energy per unit mass of fluid, the growth in the ratio of temperature and salinity fluctuations increases scintillation index, and the growth in the rate of dissipation of the mean squared temperature increases scintillation index at fixed, the stated propagation distance, primary source size, the rate of dissipation of turbulent kinetic energy per unit mass of fluid. At certain values for the propagation distance, primary source size, and the rate of dissipation of the mean squared temperature, for the smaller value of the rate of dissipation of turbulent kinetic energy per unit mass of fluid and chancing <SNR>, annular beam has more disadvantage than Gaussian beam. However, derived formulation analytically is more important for horizontal optics communication link. The results yielded in this paper can be used in the analysis of wireless optical communication links employed in ocean.

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