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DESIGN ANALYSIS OF A COMPENSATION TECHNIQUE IN FSO COMMUNICATION SYSTEM TO MITIGATE ATMOSPHERIC TURBULENCE EFFECT

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ABSTRACT

To mitigate the impact of atmospheric turbulence on free-space optical links using compensation techniquesincluding adaptiveoptical (AO) system as advanced technique.Itsthree main components have remained constant: a wavefront sensor to measure distortion, a wavefront corrector to compensate for the distortion and a control system to calculate the required correction and necessary shape to apply to the corrector.The main goal of any adaptive optical system is to show a phase correction in the arriving wavefront that converts the distorted wave front into a plane wave.We computeStandard deviation of the atmospheric tilt,DM Stroke,The residual phase variance,the turbulence strength for different telescope apertures

I.   INTRODUCTION

Free space optical systems display sharp earthly fading relate with the turbulence-induced optical amplitude fluctuations which increases the foul at the receiver and decreases the system capacity. The long-range FSOproblems. Establishing a link between ground, air, or sea-based mobile platforms in a wide variety of weatherconditions leads to severe dynamic fading and pointing errors in addition to the usual propagation losses [1].To improve link availability on long-range (>10 km) links by focusing on optical solutions,Adaptive Optics (AO) can be used to substitute static or dynamic aberrations of a light beam after generation through a corrupting medium. Generally an adaptive optical system is formative by a wave front actuator, a sensor to quantify the wave-front error and a feedback control algorithm to link these two ingredients in real time. These systems have been historically huge and high cost for wide-ranging applications [2]

Atmosphericturbulence may severe impact performance of FSO communication systems resulting in communicationlink determination shown as an increase of the bit error rate (BER) as themajor characteristic of communication system performance ,which depends on both electronic circuit related noise, and the turbulence random breaks in communication data traffic known as atmospheric signal fading[3].

II.   ADAPTIVE OPTICS (AO) TECHNIQUES

The atmospheric turbulence distorts a transmitted light beam in several ways. The beam wander distortion shifts the centroid of the transmitted beam due to the influence of turbulent cells larger than the beam. The beam spreading effect reduces the averaged intensity at the receiver by broadening the beam radius. Constructive and destructive interferences effects within a beam redistribute the intensity inside a beam. These effects can be grouped as scintillation effects. A profound study of the effects of phase and amplitude fluctuations was performed to 72 evaluate FSO coherent systems. Figure (1) showstheprinciple of wavefront correction. The incoming distorted wavefront is converted into a plane wave by introducing adaptive optics [4].
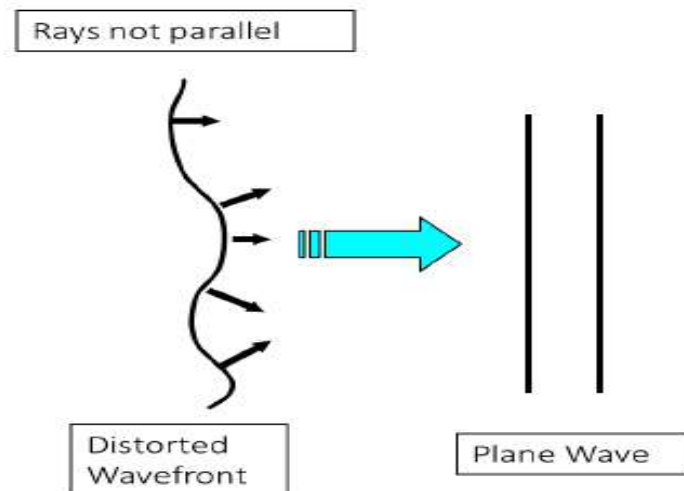
Figure (1): Principle of wavefront correctionby introducing adaptive optics

In order to decrease the level of fading and thus increase thesystem performance, adaptive optics (AO) maybe applied tothe free-space communication system. The wavefrontdistortions at the receiver aperture can be compensated by anAO wavefront corrector located at the receiver, so that the receivedlaser power can be better focused on the photo detector. The ground station of a deep space optical communicationsystem is such an example.Adaptive optics systems enhance image specific by response and rectification the phase distortion given byatmosphere.The main goalof any adaptive optical system is to show a phase correction in the arriving wave front that converts the distorted wave front into a plane wave. This project isinterested on free space optical coherent communications, which performance is severely degraded by these distortions.The atmospheric turbulent channel results into a link deterioration and an increase of the BER**.**Deformable mirrors a key component of AO systems are the deformable mirrors (DMs) that create the wanted wavefront rectification [5].

III.   DESIGN & MODELING OF (AO-FSO) COMMUNICATION SYSTEM

Adaptive optical communication systemscheme is proposed and discussed.Figure (2) shows the structure of this scheme shows first mirror acts, in conjugation with the fast steering mirror as a Z-Mirror that allows us to calibrate the system when no distortion is introduced.
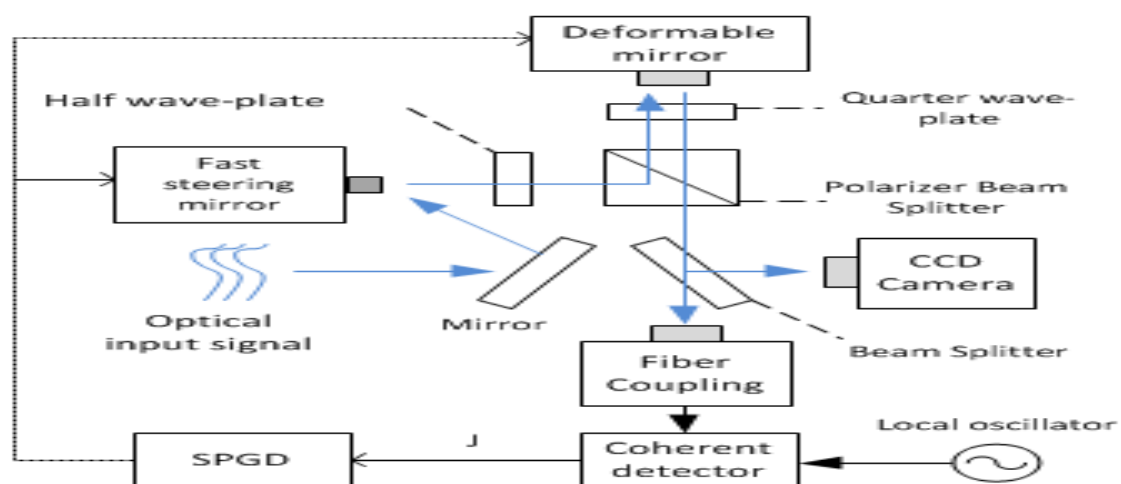

Figure (2): Adaptive AO scheme with collimated laser beam at a wavelength of 1550nm arrives to the communication link.

The light is sent through a half wave plate to modify the polarization. The output polarization must be that one that maximizes the reflection on the PBS. Then, the whole linearly polarized signal is sent to the quarter wave-

plate, which altersit to circular polarization. The light hits the DM where the handedness of polarized light is reversed and then interpretedinto horizontal polarization. A beam splitter send a sample to a CCD camera and the 92% of the power is sent to the coherent detector through a fiber coupling stage to generate the control signal to the fast and deformable mirrors [7].

One of the prime parameter to characterize the wavefront phase deviationson the aperture plane of the receiver is the phase difference. When AO is applied a correcting phase map is subtracted from the incoming phase wave front. The resulting residual difference of the corrected wave front is then expressed as [8]:

$$\sigma_{res}^2 = \frac{1}{\pi} \int (\varphi(\rho) - \varphi_c(\rho))^2 \, d\rho \quad (1)$$

Two main methods are used to describe the wavefront error over a two-dimensional aperture: zonal and modal. The modal approach is based on the principle that the actuator is ableto completely compensate j Zernike modes. Where the phase difference was expressed in terms of the normalized turbulence strength and the number of corrected modes j. the correction phase map can be defined as:

$$\varphi_{c,J}(\rho, \theta) = \sum_{j=1}^{J} \alpha_{c,j} Z_j \quad (2)$$

Where$\alpha_{c,j}$the Zernike coefficient of the correcting is phase map and $Z_j$is the j Zernike mode. The resulting residual phase error is then:

$$\sigma_j^2 = \sigma_\varphi^2 - \sum_{j=1}^{J} |\alpha_{c,j}|^2 \quad (3)$$

Where σ_φ^2 is the phase difference of the incoming signal. The residual errors, widely known as Zernike-Kolgomorov residual errors. The wave front correction is usually performed by two separated set of mirrors: first a steering mirror which performs the correction for the tip/tilt components and a deformable mirror which try to compensate higher order modes. The cause for the phase difference it is not equally distributed over all Zernike modes. Actually, by removing the first two Zernike modes, the resulting phase difference is reduced by a factor of. Assuming that modal restitution can be applied to the tip/tilt components by using a fast steering mirror, the other of the restitution is generally implemented by using zonal correction. In the zonal approach the aperture is composed by an array of independent sub apertures or areas. In each of these areas the wave front phase applied is estimated to minimize the resulting phase difference by performing a spatial average on each independent actuator. The phase difference after zonal correction is expressed by:

$$\sigma_Z^2 = \frac{1}{\pi} \int (\varphi(\rho) - \varphi_Z(\rho))^2 \, d\rho \quad (4)$$

Where σZ^2 is the phase map applied by the zonal corrector. In the section we characterize the analytical expressions to evaluate the performance of these techniques [7].
An expression to estimate the standard deviation of the atmospheric tilt as a function of the telescope aperture is given by:

$$\sigma_{title} = \sqrt{0.184 \left(\frac{D}{ro}\right)^{5/3} \left(\frac{\lambda}{ro}\right)^2} \quad (5)$$

Using the Noll's approach, the tip/tilt corrected phase wavefront presents a phase variance expressed as:

$$\sigma_{DM}^2 = \sigma_3^2 = 0.134 \left(\frac{D}{ro}\right)^{5/3} \quad (6)$$

The required actuator stroke for a deformable mirror is estimated as:

$$S_{DM} = \frac{\lambda}{2\pi} . 2.5 . \sigma_{DM} \quad (7)$$

The residual phase variance after applying zonal correction by a DM is given by(7):

$$\sigma_{res,m}^2 = k \left(\frac{rs}{ro}\right)^{5/3} \quad (8)$$

IV.   SIMULATION RESULTS & DISCUSSIONS
This design study was based on an advanced computer program allow to carry out thefield FSO system characterization and performance measurement under a various levels of turbulences.Figure (3)showsσ**tilt** as a function of the coherence length **r₀** for wavelength 1550nm and different telescope apertures when D= (20, 60,

80, 100) cm respectively. The maximum atmospheric Tilt can be expressed as:$M_{tilt}= + \sigma_{tilt}$, so for the given apertures and considering realistic values of >10 mm, the maximum tilt is around 1mrad. Also we need to include a 0.5 factor due to the fact that an angular movement of the mirror corresponds to twice the beam angular shift. Assuming that no amplification is used, the maximum angular depletion needed in our system is ±0.5mrad.
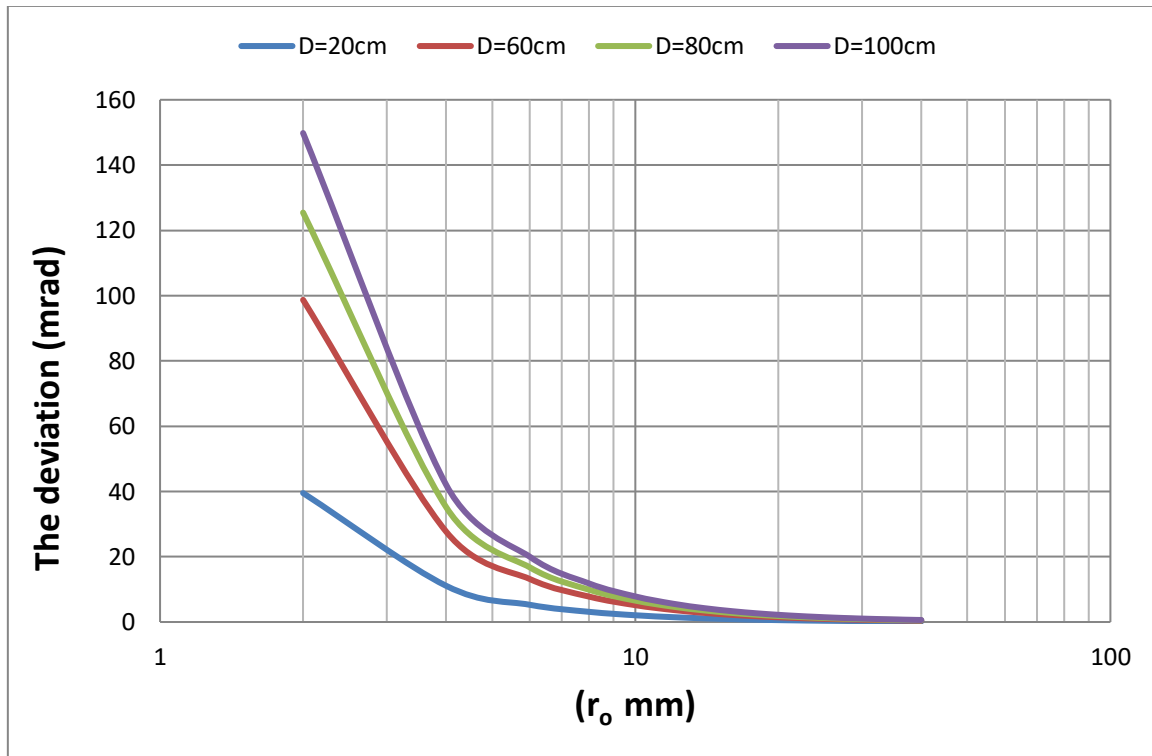

Figure (3): Standard deviation of the atmospheric tilt versus of the coherence length r_0 for wavelength1550nm and different telescope apertures

The required DM Stroke for compensating tip/tilt corrected wave fronts as a function of the normalized turbulence strength is shown in Figure (4).
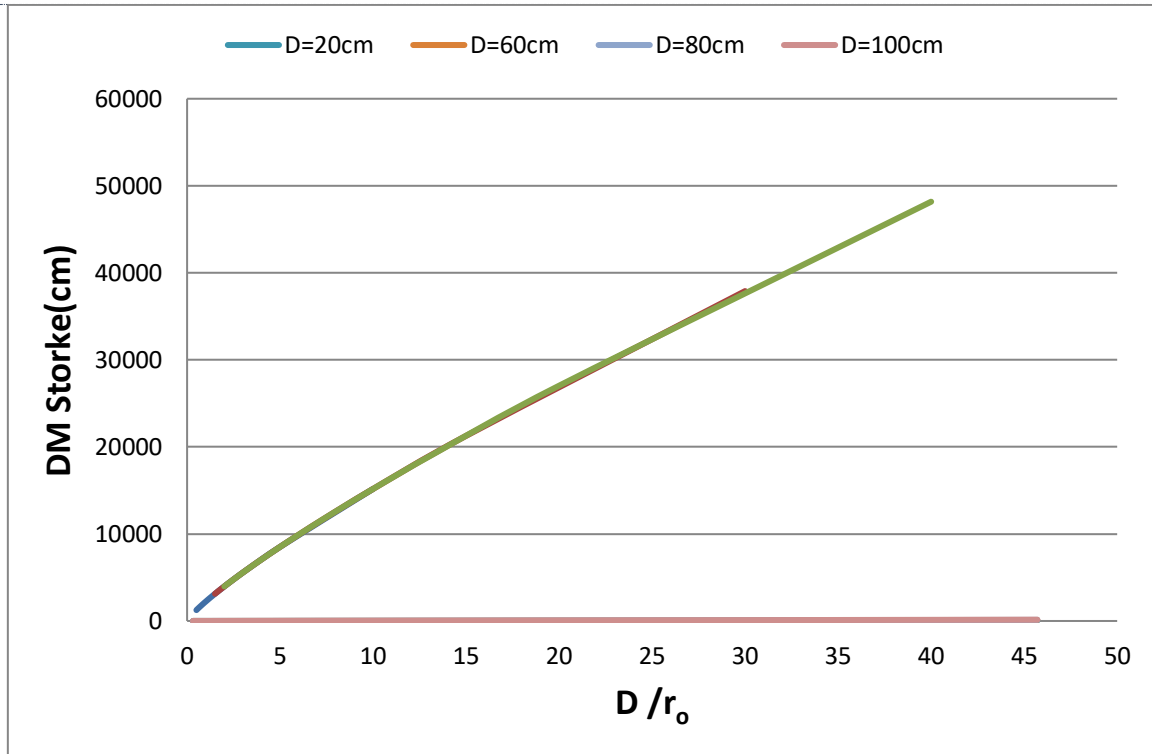
Figure (4): DM Stroke required for compensating tip/tilt corrected wave fronts versus the normalized turbulence strength

The residual phase variance as a function of the Fried parameter r_o and the interactuator spacing r_s is shown in Figure (5).
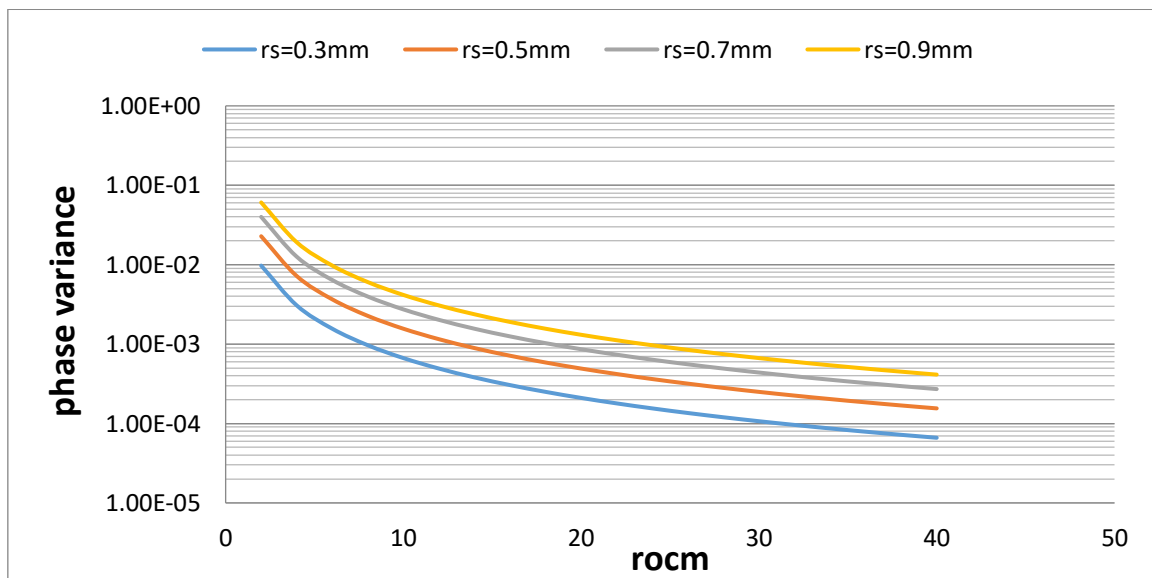

Figure (5): Residual phase variance aversus of the Fried parameter $r_o$and the interactuator spacing rs for typical values of $r_o$between 2 and 40 cm and rs (0.3,0.5,0.7,0.9)mm ,k=0.23

Standard deviation of the atmospheric tilt as a function of the turbulence strength for different telescope aperturesis shown in Figure (6).
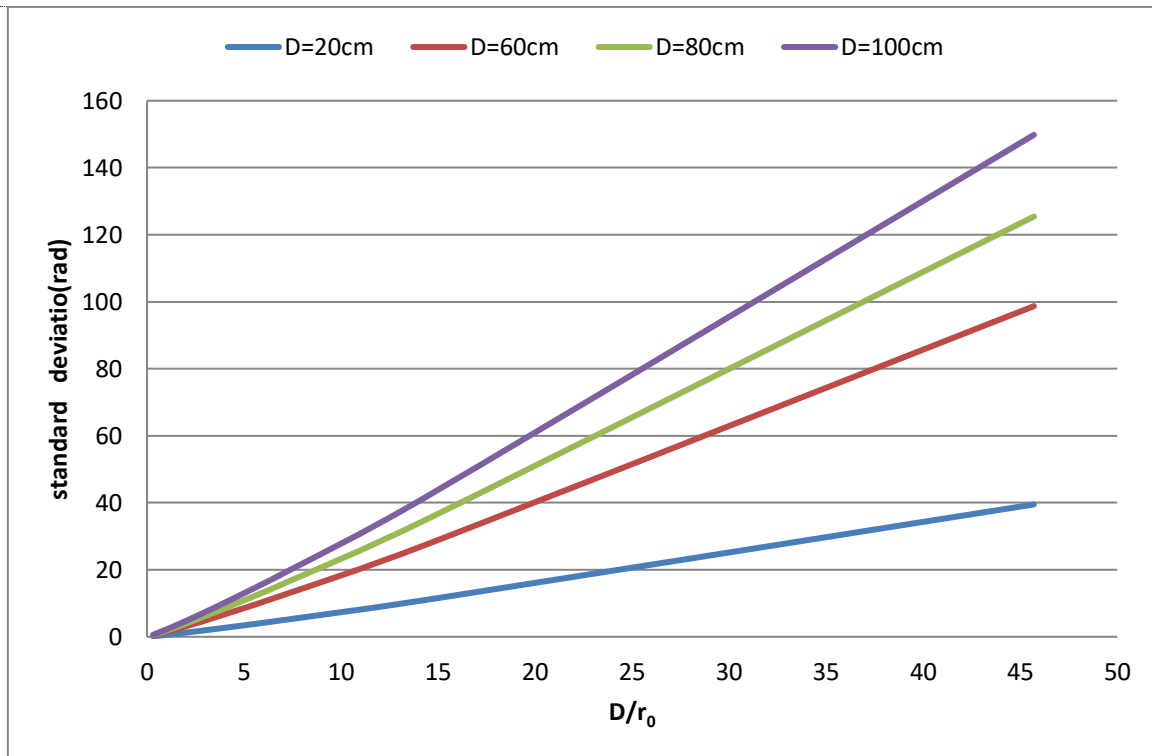
Figure (6): Standard deviation of the atmospheric tilt as versus of the turbulence strength for different telescope apertures

Residual phase variance asa function of the turbulence strength for different telescope apertures is shown in Figure (7).
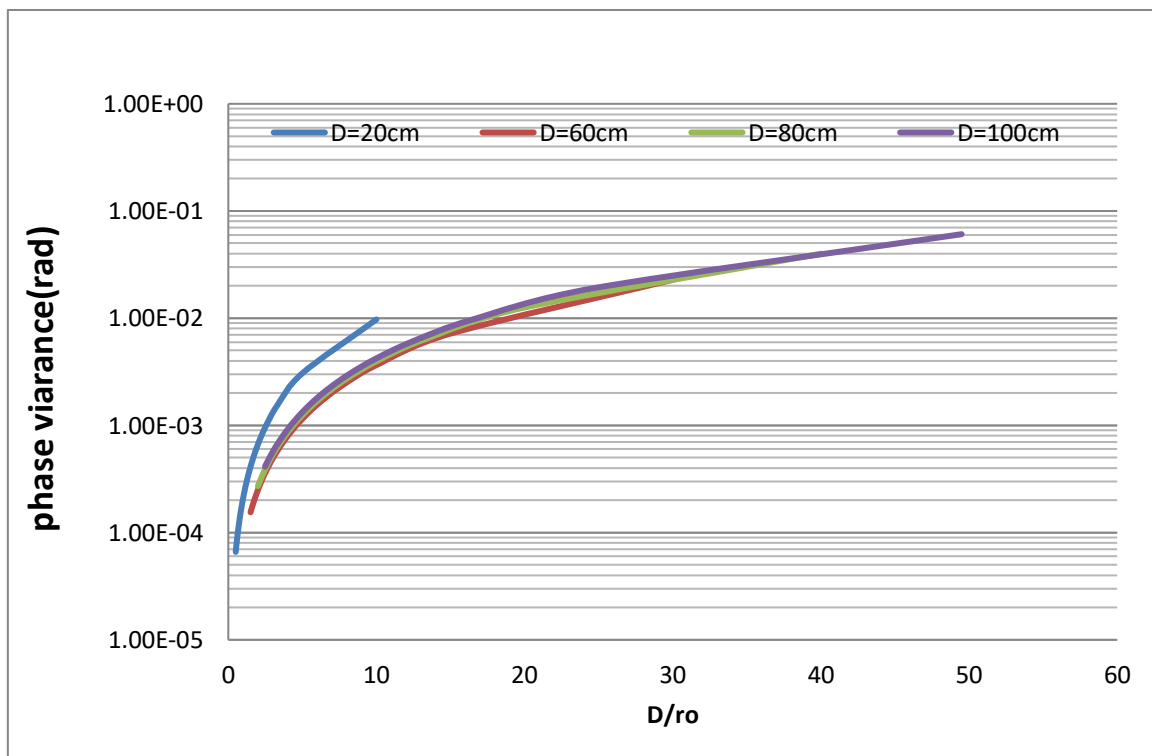

Figure (7): Residual phase variance asversus of the turbulence strength for different telescope apertures

V.   CONCLUSIONS

The effect of atmospheric disturbances in free space optical links was studied using compensation technique, including adaptive optics.Standard deviation of the atmospheric tilt as versus of the coherence length r_o and different telescope apertures, Residual phase varianceversus of the Fried parameter r_o and the interactuator spacing r_s, DM Stroke required for compensating tip/tilt corrected wave fronts, Standard deviation of the atmospheric tilt, Residual phase variance versus the normalized turbulence strengthfor different telescope apertures for wave length 1550nm.

VI.   REFERENCES

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