Free-space data transfer using the spatial modes of light

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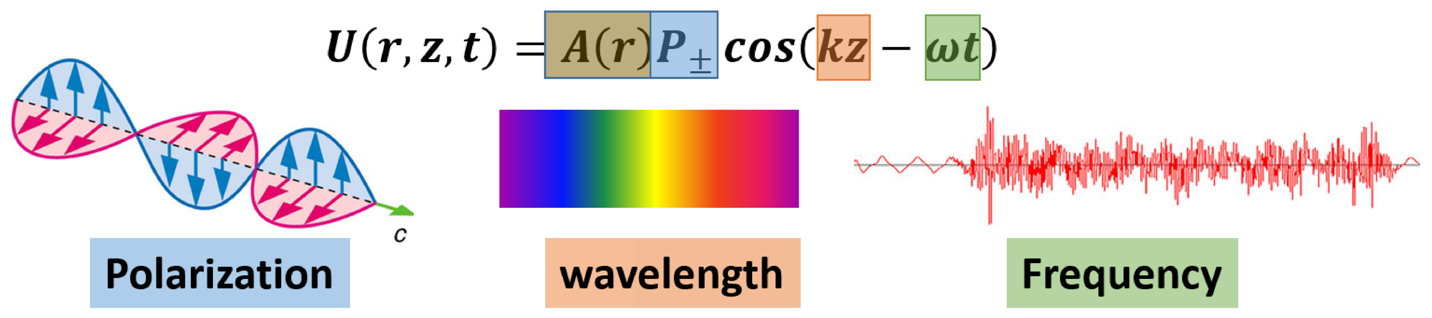
ABSTRACT

The orbital angular momentum (OAM) of light has become the focus of intensive research. Traditional optical communication systems optimize multiplexing in the polarization and the wavelength of light to attain an increase in bandwidth. However we are expected to reach a bandwidth ceiling in the near future [1]. For this reason we are interested in the spatial degree of freedom that light can provide for optical communication. These spatial modes carry integer values of OAM where by there is no theoretical limit. We demonstrate the generation and detection of these modes by making use of a Spatial Light Modulator (SLM). This work was done in a lab-based scheme, free from the challenges associated with atmospheric turbulence. We wish to extend this work to the mid-IR region as an attempt to reduce the problems associated with atmospheric turbulence over a long-distance communication link and show high bit-rate data transfer.

DATA TRANSFER USING LIGHT BEAMS WITH A "TWISTED" WAVEFRONT

Traditional optical communication systems optimize multiplexing in the polarization, wavelength and frequency of light but it was not until two decades ago that light fields with an azimuthal phase dependence were shown to carry OAM of $l\hbar$ per photon [2]. The number of "twists" corresponds to the OAM number "*l*" or the topological charge. Holograms encoded on a SLM are used to impart an azimuthal phase into a flat wavefront.

$$U(r,z,t) = A(r)P_{+}\cos(kz-\omega t)$$



$$C = XYZ \times number\ of\ channels$$

Fig 1- Modulation in polarization, wavelength and frequency were employed by tradition optical systems to modulate light and send information. Currently these modulation schemes are employed together with OAM to achieve higher bandwidth or the link capacity

The azimuthal index "l" spans an infinite dimensional Hilbert space, theoretically allowing an infinite amount of information to be encoded but due to experimental limitations we are bounded. Keeping current modulation techniques we can increase the bandwidth *n* times were *n* is the number of channels in each channel we can have wavelength, frequency modulations.

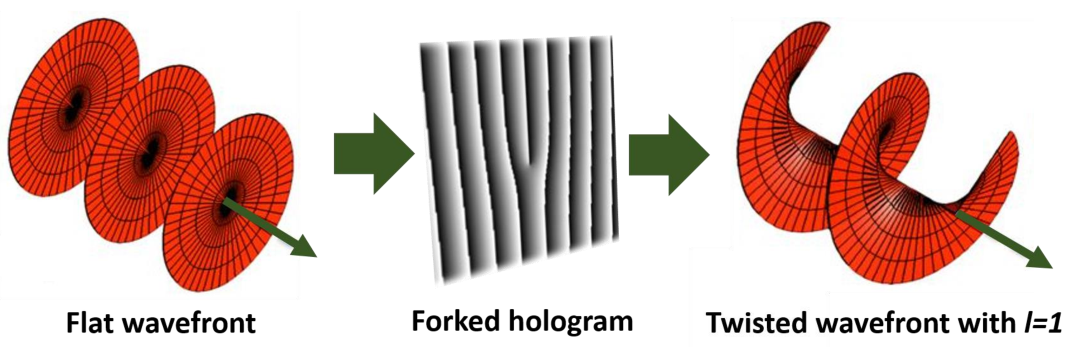


Fig 2- A collimated beam with a flat wavefront propagating in space gains OAM of *l* =3 as is passes through a spiral hologram.

GENERATION AND DETECTION OF TWISTED LIGHT BEAMS

A SLM was used to generate and detect OAM modes. These devises work by modulating the phase of a horizontally polarised light. A Complex amplitude modulation technique was employed to give phase and amplitude modulation on a phase only SLM [3]. We require a scalar field of $s(x,y) = a(x,y)e^{i\phi(x,y)}$ where "a"and "ϕ" are the amplitude and phase terms respectively and by employing a hologram of the form $h(x,y) = e^{i\psi(a,\phi)}$ provides the desired complex amplitude modulation.

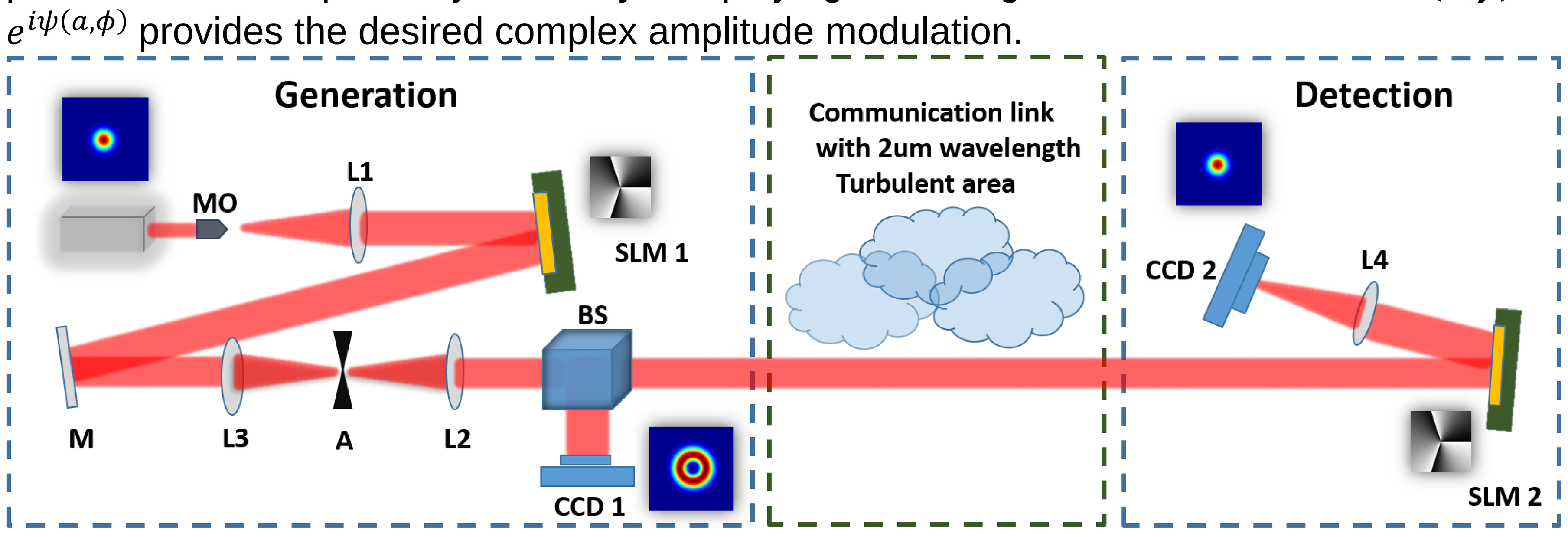
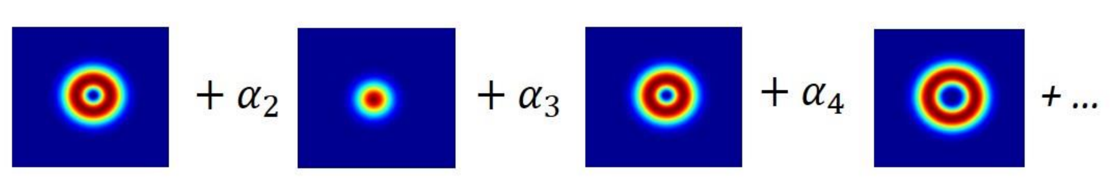


Fig 3 - **Generation and Detection of twisted beams**: A linearly polarized HeNe laser was expanded and collimated by a 10x Microscope Objective (MO) and a lens L1 (F=100mm) and directed onto a SLM 1 for complex amplitude modulation. The generated modes were spatially filtered by aperture (A) in the 4F system made up lens L2,L3 (F=150mm)then imaged into the CCD camera. The intensity distribution observed on CCD1 imaged onto SLM 2 via the beam splitter (BS) were detecting holograms were encoded. Modal decomposition was carried out and lens L4 performs a Fourier transform of the match filter (SLM 2) and incident mode and the optical inner product is measured by CCD 2.

In modal decomposition we express a light field as a superposition of orthogonal bases functions. Using the orthogonality of the bases functions we can calculate the complex modal coefficients $\alpha_n = c_n e^{i\Delta\varphi_n}$ where c_n is the modal amplitude and φ_n is the relative phase.

$$\varphi(x,y) = \sum_{n=1}^{\infty} \alpha_n \psi_n(x,y) = \alpha_1 \square + \alpha_2 \square + \alpha_3 \square + \alpha_4 \square + \ldots$$



This technique is achieved by encoding complex conjugate holograms onto SLM 2 and together with L4 they form a correlation filter which detects the encoded modes from SLM 1 depending on the power signal on CCD 2 we can identify the mode.

EXPERIMENTAL RESULTS

Spatial modes were prepared by complex amplitude modulation encoded on SLM1. Figure 4C depicts 5 modes that were selected to represent a grey scale, 100X100 pixel picture of Maxwell which was sent and recovered via SLM 2 by modal decomposition with very high fidelity.

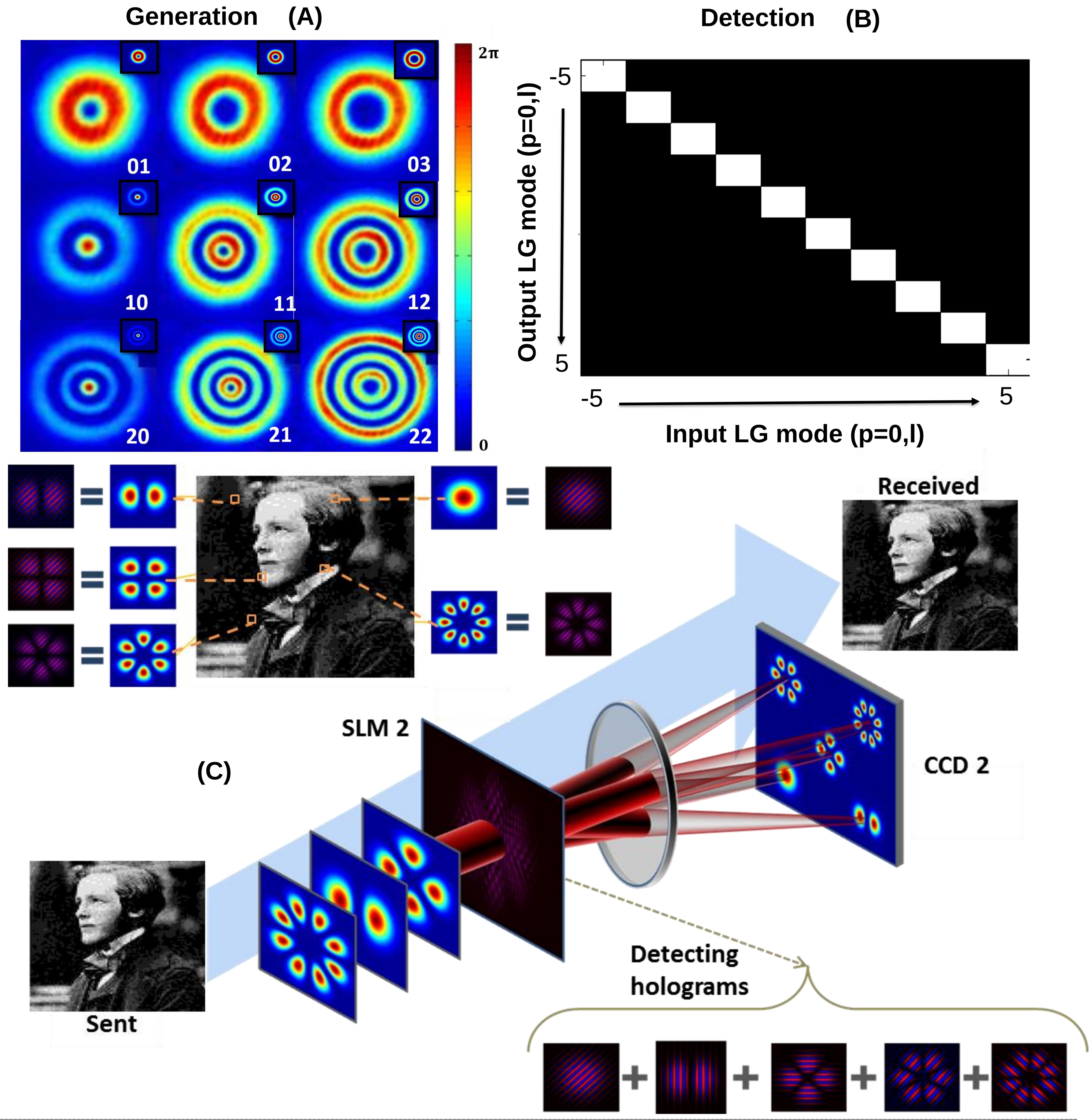


Fig 4- (A) Shows modes generated by SLM 1 using complex amplitude modulation and at the top right corner are numerical simulations of the intensity distribution, (B) modes detected in SLM 2 by modal decomposition, (C) Sent and recovered image of Maxwell by combination of complex amplitude modulation and modal decomposition .

LONG DISTANCE DATA TRANSFER IN THE MID INFRARED REGION

This work was done in a turbulent-free environment with a 633nm HeNe laser. Since signal hindering factors arise when one tries to send information outside a lab-based scheme, we propose establishing a 150 m communication link that will make use of a 2 um source and SLM. The 2um source will allow us to transmit signals through the atmosphere with less atmospheric attenuation due to fog, rain, mist, dust and aerosol scattering. This work will also incorporate non-diffracting long-range Bessel beams which remain diffraction-free over extended distances. In fig 3 the same experimental setup will be employed and now this will have a propagation distance in a turbulence prone environment as shown in the green highlighted box.

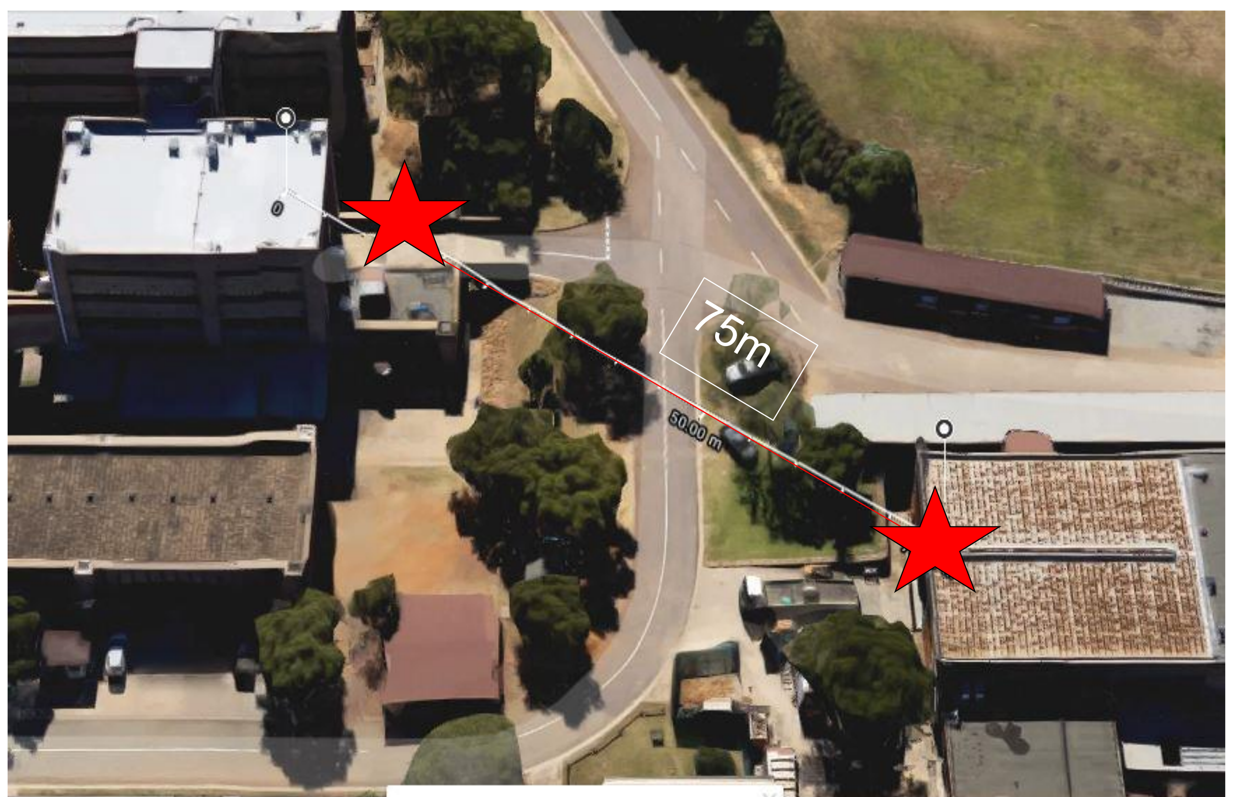


Fig 5- Communication link to be realised inside the CSIR campus between two buildings F-block and A- block which will extend to over 150m

REFERENCES

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