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Rectangular Waveguide Polymer Microwave Fiber (PMF) Interconnect for Satellite Communication Systems

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ABSTRACT

Research in millimeter-wave dielectric waveguides is recently experiencing high interest in efficient data communication. Generally, channel interconnect remains a challenge for high-speed links design in satellite communication. This paper presents an analysis of Polytetrafluoroethylene (PTFE) interconnect at Ku band owing to its low-cost and efficient throughput. The effect of varying PTFE properties was examined based on the wavelength, propagation constant and attenuation, in other to advise on coating and energy escape outside the Polymer Microwave Fiber (PMF).

Key words: Ku Band, Polymer microwave fibers (PMF), Attenuation, dielectric waveguide and millimeter wave (mm-wave).

1. INTRODUCTION

The continuous demand for high-speed, low-cost and energy efficiency data links for interconnect in today's electronic systems is growing interest in millimeter and subterahertz dielectric waveguides for data communications. In today's technology, bit rates up to 20 Gbps are achieved over a pair of metal conductors over short distances [11].

A polymer fiber is a light-weight and low-loss channel at millimetre-wave (mm-Wave) frequencies. Polymer microwave fiber (PMF) is a promising[2], robust and low-cost technology to complement copper or optical links for high-speed applications with transmission distances up to several meters. These dielectric waveguides show promising properties such as low attenuation (1–5 dBm−1) and high bandwidth for high-speed communication (1–20 Gb/s)[1].Hence, this rapid development is being explored to increase the bit rate of data communication links. The communication distances are also limited because of the large free-space path loss (FSPL) at these frequencies [1]. This imposes serious constraints on power consumption, cost, and footprint of optical interconnects.

In literature, Optical fibers as interconnects do not suffer from similar bandwidth limitations or crosstalk issues. However, they require additional electrical-to-optical (EO) and optical-to-electrical (OE) conversion devices for the generation and detection of optical signals [10].

The wires and connectors limit mechanical design flexibilities and the physical and topological challenges of such wired interconnect can affect the system performance and reliability [8].Hence, the loss of the fiber increases for increasing frequencies and the bending losses decrease with increasing frequencies.

A cheaper and more power-efficient approach is to use a polymer microwave fiber (PMF) as the transmission channel for mm-Wave data communication [2]. This act as a low-loss channel for mm-Wave radio signals [4], creating an alternative technology, complementary to optical and copper wireline.

For link distances up to 10 meters, a PMF link appears to be a valuable alternative that can reach high data rates with a competitive link energy efficiency.A dielectric waveguide does not need to be connected electrically like the wire or aligned to micron-level accuracy like optical fibers. It can be bent and twisted without a significant impact on signal integrity.

Hence, there is a need to satisfy small area, low cost and power consumption requirements while providing enough transmission range between the chips and the boards.

2.RELATED WORK

Flexible Polymer microwave fibers (PMF) are available in a large variety of geometries, materials and dimensions.

The PMF channel guides the modulated waveform from the transmitter to the receiver. The operating band is Ku-Band (12GHz-18GHz) which features large bandwidth and high data rates for data communication most especially in satellite communication.

Waveguides are hollow pipes, and may have either circular or rectangular cross sections.

Rectangular are, by far, the most common. These waveguides are used for high frequency transmission in the gigahertz (microwave) range. The higher modes in the form of transverse electric (TE) and transverse magnetic (TM) modes propagates in the waveguide as shown in Figure 1.

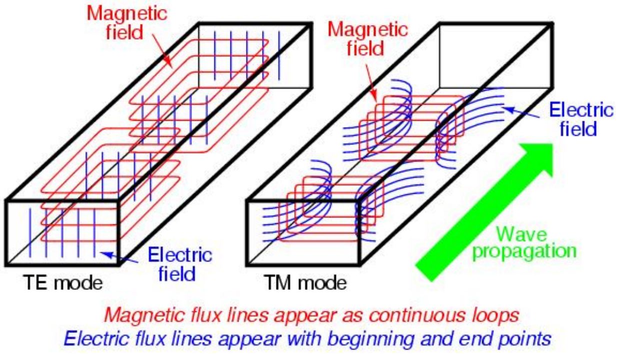

Figure 1:TE and TM wave propagation showing the electromagnetic fields

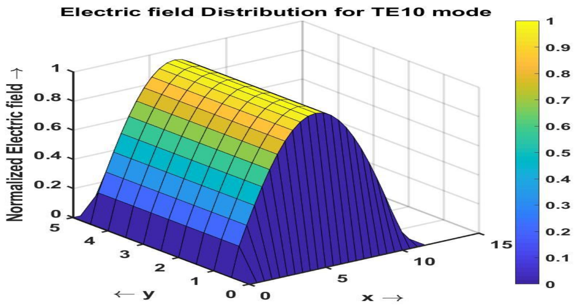

Figure 2: Rectangular waveguide TE10 dominant mode

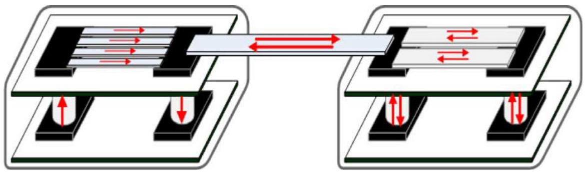

Figure 3:Chip-to-chip interconnects and board-to-board interconnect[5]

The TE_{10} is the dominant mode of a rectangular waveguide with a>b, since it has the lowest attenuation of all modes as shown in Figure 2.

Figure 3 shows an example of chip-to-chip and board-to-board interconnects applying the plastic waveguide interconnect. The bi-directional transmission can be achieved using millimeter wave signaling and the use of multiple carriers over the bandwidth of the waveguide [[1]]-[7]

In this paper, a rectangular waveguide Polytetrafluoroethylene (PTFE) is used considering the permittivity and permeability of the material.

The dimension of the waveguide a=12.5mm and b=6.79mm was derived from both equation (1) and(2)of the cutoff frequency (f_c)is 8.313GHz and cutoff wavelength for TE_{10} when m = 1 and n = 0 as shown in Figure 6.

Considering the frequency band of operation which is Ku band, (12GHz- 18GHz), the wavelength range is 2.5 – 1.67cm.

$$fc_{10} = \frac{1}{2a\sqrt{\mu\varepsilon}} \qquad (1)$$

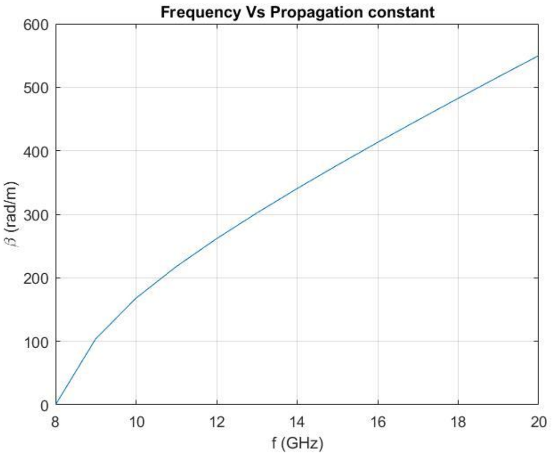

Figure 4: Simulation of the propagation constant of the fundamental mode in the dielectric waveguide

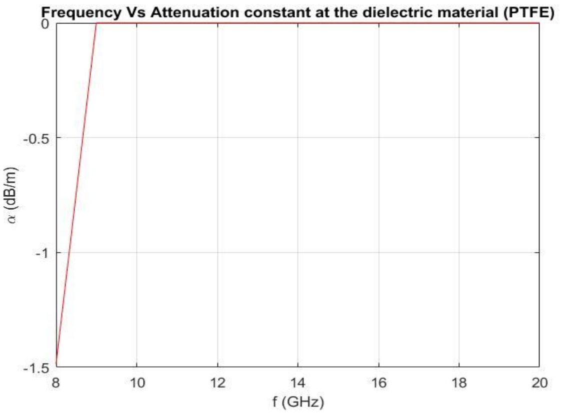

Figure 5: Simulation of attenuation at permittivity of the dielectric PTFE material.

$$(\lambda_c)_{mn} = \frac{2}{\sqrt{(\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2}} \qquad (2)$$

Permeability of PTFE material (μ) = 1.2567×10^{-6}.

Permittivity of PTFE material (ε) =18.42×10^{-12}.

This technology is explored in Ku Band to achieve a high data rate at low noise for satellite data communication [[7]]-[[11]]. The cutoff frequency at this frequency of operation is 8.313GHz which is shown in figure 4 and figure 5.

Designing fibers for PMF communication means finding a balance or trade-off between attenuation, dispersion, bending loss and field decay [12]. The transmitter and receiver in laser communication must require line-of-sight conditions [[14]].

3.PROPOSED MODEL

At the operating frequency, the propagation constant of the rectangular waveguide with the given dimensions a and b using the wave equations (3) and (5) is derived for this design. The k_{cTE10} is the critical (cutoff) wave number that guides the wave's frequency wave number for TE_{10}mode is:

$$K_{cTE10} = \sqrt{(\frac{m\pi}{a})^2 + (\frac{n\pi}{b})^2} \qquad (3)$$

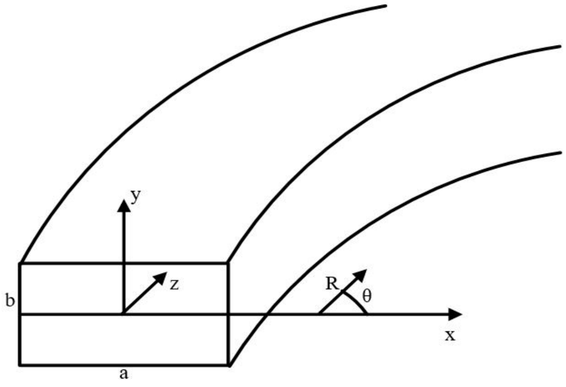

Figure 6: Geometry of bending rectangular waveguide
R = radius of bending; a = width (along x axis); b = height (along y axis); z = length of waveguide propagation
θ = angle of bending

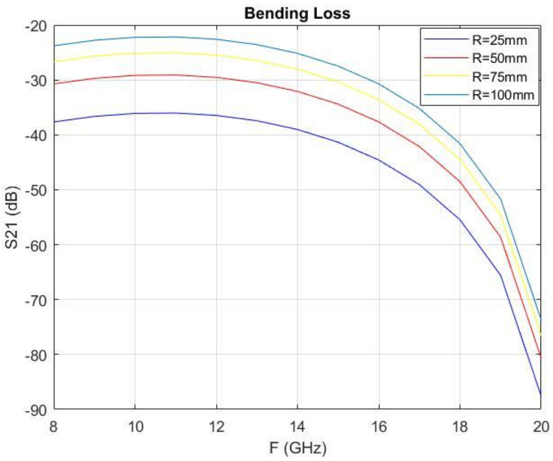

Figure 7:Bending loss of PTFE rectangular waveguide for different radii

The wave number;

$$K_o{}^2 = \omega\sqrt{\mu\varepsilon} \qquad (4)$$

The Propagation constant;

$$\beta = \sqrt{K_o{}^2 - K_{cTE10}{}^2} = \sqrt{\omega^2(\mu\varepsilon) - (K_{cTE10})^2} \qquad (5)$$

The simulated propagation constant for the waveguide is shown in figure 4. As the frequency drops, it deviates more and more from the Marcatili approximation.

According to the approximation, each mode has a lower cutoff frequency. This is due to the fact that the approximation is only valid as long as most of the guided power is inside the waveguide [13].

The dielectric attenuation constant of the rectangular waveguide as shown in figure 5 is derived from equation (6);

$$\alpha_d = \frac{k^2 tan\delta}{2\beta}\ Np/m \qquad (6)$$

$tan\delta$is the loss tangent of the PTFE which is 0.0004, k and β are the wave number and propagation constant respectively.

Figure 5 shows the simulation of attenuation constant α for the PTFE rectangular waveguide.

4.RESULTS AND DISCUSSIONS

Considering the dielectric waveguide bendat a radius R, as indicated in figure 6.The bending loss affects the signal propagation down the waveguide lengthas shown in figure 8.

$$\gamma_x = \sqrt{\beta^2 - k^2} \qquad (7)$$

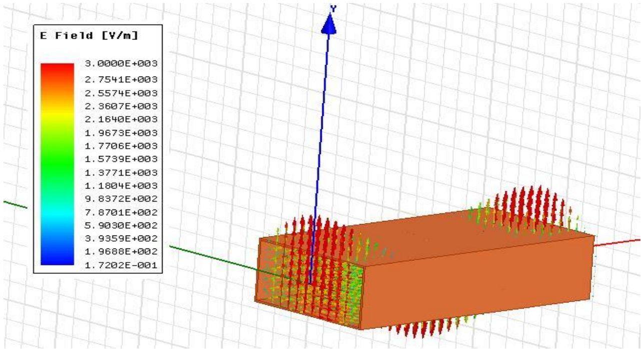

Figure 8: TE10 mode PTFE rectangular waveguide propagation

$$\alpha = \frac{\lambda\gamma_x^2}{\pi n(\gamma_x d+2)} cos^2\left({}^{k_c d}/_{2}\right) e^{\gamma_x d} e^{-2\gamma_x\left({}^{\beta}/_{k}-1\right)R} (8)$$

From equation (8) above, the bending loss is derived considering the waveguide width, wave number, cutoff wavenumber and the various radius of bending and shown in figure 7. To keep this loss the same for each bending radii, the total length of the waveguide is kept constant. The bending losses decrease with increasing frequencies. This is proof that higher operating frequencies is preferred when using PMF technology.

5.CONCLUSION

In this paper, attenuation, propagation constant and bending loss of the rectangular PTFE waveguide has been examined.

At lower frequency, more energy will be outside the dielectric fiber, while this causes more constraints on the shielding or coating which can be done using another dielectric material, dielectric foam or metal.

Future work involves power loss in the dielectric material along the propagation path, scattering and decay.

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