# MILLIMETER- AND SUBMILLIMETER-WAVE ELECTRODYNAMIC PROPERTIES OF POLYMER ELECTRO-OPTIC MATERIALS

Mark Lee, Oleg Mitrofanov, and Howard E. Katz
*Bell Laboratories, Lucent Technologies, 600 Mountain Ave., Murray Hill, NJ 07974*

The bandwidth of commercial optical telecommunications technology has recently crossed into millimeter-wave frequencies (*i.e.* 40 GHz), and there is now a strong research effort aimed at extending these bandwidths deeper into millimeter-wave and perhaps even into submillimeter-wave frequencies. Materials with electro-optic optical non-linearities are inherent in such communications systems, since they allow a voltage signal to amplitude or phase modulate an optical carrier. Alternatively, an electro-optic material can be used in conjunction with optical interferometric techniques to form a phase-sensitive detector of THz waves. The ferroelectric perovskites most commonly used as electro-optic materials up to 40 GHz have crippling limitations that render them unusable at bandwidths exceeding 80 to 100 GHz.[1] Therefore, there has very recently been a resurgence of interest in the non-linear optical properties of conjugated polymer-based materials. The very fast and nearly lossless electron transfer along $\pi$-conjugated bonds in such polymers promise a very high intrinsic frequency response with little index dispersion over a very broad bandwidth. Also, recent progress in the chemical synthesis of electro-optic polymers[2] has resulted in materials with electro-optic coefficient as high as 75 pm/V, or greater than three times that of $LiNbO_3$, which is the most widely used electro-optic material today.

Using a combination of vector network analysis and pulsed THz time-domain spectroscopy, we have measured the real and imaginary dielectric properties of several different polymer host matrices and polymer electro-optic chromophores across the frequency range 0.05 to 600 GHz. All these polymer materials have very desirable properties for use as either electro-optic modulators or detectors at millimeter- to submillimeter-wave frequencies. The indices-of-refraction measured are all fairly low, in the range of 1.3 to 2.0 for all materials, and show very little dispersion up to at least 200 GHz and even up through 600 GHz in at least one case. Moreover, these index values are within approximately 15% of the corresponding optical indices at 1.5 μm wavelength for each polymer, making the engineering of high-efficiency velocity-matched collinear optical and millimeter-wave waveguides much simpler than with perovskite materials. Finally, these polymers have very small dielectric loss tangents up to at least 250 GHz. Typical loss tangents are comparable to, and in some cases smaller than, the loss tangent of a Teflon reference in this frequency range. Therefore, we expect negligible parasitic dielectric loss in millimeter-wave electro-optic devices made from these materials.

As an example of a very wide bandwidth electro-optic device, we have also designed, fabricated, and tested a prototype polymer optical modulator with optical response bandwidth exceeding 200 GHz.

---

[1] Mark Lee, Appl. Phys. Lett. **79**, 1342 (2001)

[2] Y. Shi, C. Zhang, H. Zhang, J. H. Bechtel, L. R. Dalton, B. H. Robinson, and W. H. Steier, *Science* **288**, 119 (2000)