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Polymer Properties for High-Gain Microwave Antennas

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Summary

Polymers intended for microwave antennas should have a dielectric constant between 1.5 - 3.0 and tan δ loss factor less than 0.001 for high-gain, small beam-width operation. Desirable antenna properties are obtained by polymerizing the monomer using UV and γ-radiations compared to polymerization with the use of initiators. The polymer should be able to withstand shock, vibration and high ambient temperature. Teflon has proved to be the polymer of choice followed by polystyrene, perspex, nylon, polypropleyne and polyacetal.

Introduction

A dielectric polymer rod can act as a guide of electromagnetic waves especially in the microwave frequency region. Properly designed polymer end-fire antennas can realize gains in excess of 18 dB in the 8.5-12.8 GHz frequency range(1-4). The gain-frequency characteristics are directly dependent on the dielectric constant E_r and tan δ loss factor of the polymer. The polymers studied for antenna applications are perspex, teflon, polystyrene, nylon, polypropleyne and polyacetal.

This paper reports the properties of polymers necessary for high-gain microwave antennas. A comparative study of the suitable polymers is made in relation to the gain-frequency characteristics in the X-band(8.5-12.8GHz). Polymer circular and rectangular antenna requirements are also discussed.

Effect of E_r on gain

The polyrod antenna gain and radiation characteristics are dependent on the diameter d, and is a function of E_r. For a given polymer the rod diameter determines the wave velocity v, and the gain is optimized when v, and the antenna length l

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satisfies the Hansen-Woodyard condition(5). It has been established that a polyrod antenna realizes maximum directive gain when

$$d = \lambda_0 / \sqrt{A\pi\,(E_r - 1)}$$

where A is a constant to be determined for a polymer at the free-space wavelength λ_0. Typical values of A for perspex(E_r=2.56) and teflon(E_r=2.1) at 10.0GHz are 1.51 and 1.15 respectively. Since $d \propto 1/\sqrt{E_r}$, it follows that a large E_r results in small diameter of the antenna. This is not desirable particularly in operating conditions subjected to shock, vibration and high ambient temperature. Our studies show that E_r values in the range 1.5-3.0 are suitable for microwave antennas. Polymers with these E_r values are nylon, teflon, perspex, polystyrene, polypropleyne and polyacetal. For wide frequency operation the dielectric constant should not vary by $\pm 2\%$ in the frequency spectrum at which the application is desired.

Effect of tan δ on gain

The gain of the antenna is also affected by the length and tan δ of the polyrod. It has been observed that antenna length between 6-8 wavelengths realizes optimum gain and small beam-width. The attenuation of microwave power inside the polymer is related to l, E_r and tan δ loss factor by the expression,

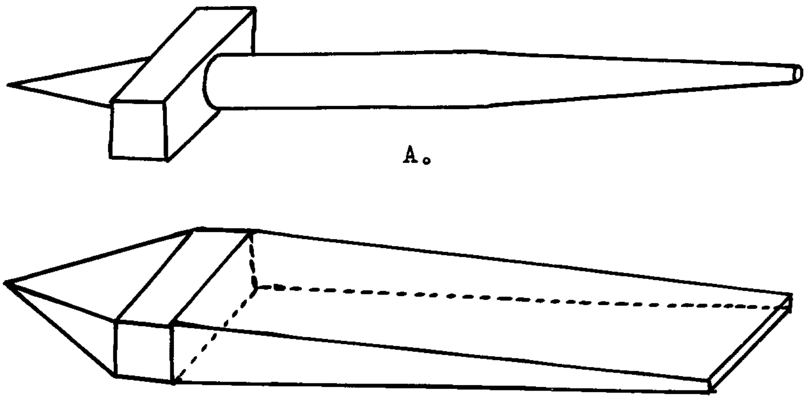
$$\alpha = (27.3/\lambda_0) . \sqrt{E_r} . \tan\delta \quad \text{dB/cm.}$$

To minimize attenuation it thus becomes necessary to select a polymer with small E_r and tan δ, and also the antenna length. A 6.5 wavelenth long antenna using a polymer with E_r=2.0 and tan δ =0.001 attenuates the signal 0.014 dB/cm. at 10.0GHz. Clearly, antennas with l = 6 - 8 wavelengths utilizing polymers with $E_r \leq 3.0$ and tan δ less than 0.001 should be used to minimize attenuation losses and thereby increase the directive gain of the antenna.

It is also desirable that the polymers with suitable E_r and tan δ values be adaptable for fabrication into antennas of various profiles. Figure 1 shows the profile of high-gain optimized circular and rectangular polymer antennas. The polymer should be able to stand ambient temperatures upto 100°C without changing form and electrical parameters. For moulded antennas it is preferable that the monomer be polymerized without the addition of initiators as this has adverse effect on the dielectric properties. UV and Co^{60} gamma radiated monomers have resulted in stable polymers (1).

Experimental

Circular and rectangular polymer antennas as shown in Figure 1 were designed for X-band frequencies



A.

B.

Figure 1 Optimized high-gain microwave polymer antennas. A. Circular and B. Rectangular

using various polymers. Maximum directive gain of 18.5 dB was obtained for teflon rectangular antenna in the 9.5 - 10.5 GHz frequency range. The gain obtained for the teflon circular antenna in the same frequency range was 16.5 dB. Table I gives the gain obtained for circular antennas using various polymers.

TABLE I

Polymer	poly-styrene	nylon	perspex	poly-propleyne	poly-acetal
Gain,dB	16.65	16.2	15.0	14.4	14.3
-3 dB beam-width,	20°	16°	19.6°	21.2°	18°

The input impedance of the teflon antenna does not vary appreciably with frequency and this is reflected in the wide-band operation with fairly stabilized gain.

Conclusions

Teflon (PTFE) microwave antennas realize high gains and small beam-widths. They can withstand high ambient temperature and vibration without any degradation in gain. Teflon is easily machined and is not affected by atmospheric corrosion. Polymers intended for antennas should have E_r = 1.5 - 3.0 and tanδ loss factor less than 0.001. Other polymers found suitable are perspex, nylon, polystyrene, polypropleyne and polyacetal.

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