Although the one-way loss of the final accelerator was 7 dB, so that a resonance technique would have been meaningless, the final measurements were easily made to a precision of 3° in phase and 2 percent in amplitude.

The reflection measurement is now being used by R. P. Borghi as a final test after tuning on all accelerator sections produced for SLAC (approximately 1000 ten-foot sections).

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Improved Response of Pyroelectric Millimeter Wave Detectors

Pyroelectric materials such as triglycine sulfate (TGS) and barium titanate have been investigated for possible use as millimeter and submillimeter wave detectors [1], [2]. The primary limitation of pyroelectric detectors appears to be its response time since its sensitivity is suitable for many applications, e.g., microwatt range at submillimeter wavelengths. The best reported response time thus far is on the order of 30 microseconds [1] for TGS at room temperature.

The purpose of this correspondence is to show that the response time of the detector can be easily reduced better than an order of magnitude, i.e., in the range of 2 microseconds. This improvement allows the detector to be useful in some high speed video millimeter and submillimeter applications.

The following analysis shows that the pyroelectric voltage generated by an incident modulated wave is, in the small signal linear case, proportional to the time integral of the power modulating function.

After Chynoweth [3], the displacement current density of a single crystal pyroelectric material due to a temperature/time gradient is

$$\bar{J} = \frac{\partial \bar{P}_s}{\partial T}\frac{\partial T}{\partial t}, \tag{1}$$

where $\bar{P}_s$ is the spontaneous polarization vector, T is the absolute temperature, and t is the time.

The change in temperature with respect to time being the typical calorimeter problem, we have, therefore,

$$\frac{\partial T}{\partial t} = \frac{1}{m'C_pJ_1}\frac{\partial H(t)}{\partial t}, \tag{2}$$

where m' is the active mass of the crystal,[1] C_p is its specific heat, J_1 is the mechanical equivalent of heat, and $H(t)$ is the heat energy. Since the change in heat energy with time is just the power dissipated in the crystal, we have

$$\bar{J} = \frac{\partial \bar{P}_s}{\partial T}\frac{P(t)}{m'C_pJ_1}. \tag{3}$$

The primary interest is in the polarization plane, therefore

$$J_p = \hat{n}\cdot\bar{J}; \tag{4}$$

also since there is assumed to be no conduction current

$$J_p = \frac{dD_p}{dt} = \epsilon_p\frac{\partial E_p}{\partial t}, \tag{5}$$

where $\hat{n}$ is a unit vector in the polarization plane, ϵ_p is the component of the complex permittivity tensor along the polarization plane, and E_p is the developed pyroelectric field.

For a rectangular crystal of thickness (τ), we have, by combining (4) and (5) and integrating,

$$V_p(t) = \hat{n}\cdot\frac{\partial \bar{P}_s}{\partial T}\frac{\tau}{\epsilon_p m'C_pJ_1}\int P(t)dt, \tag{6}$$

where $V_p(t)$ is the pyroelectric potential. Now for an incident wave which is amplitude modulated we have

$$P(t) = M(t)P_0\exp(-2\alpha z), \tag{7}$$

where P_0 is the time average power at the inner surface of the crystal, $M(t)$ is the power modulating function, α is the attenuation coefficient, and z is the depth into the crystal. We have upon substitution of (7) into (6)

$$V_p(t) \propto \int M(t)dt. \tag{8}$$

Essentially, we then have a case where the output of the detector is proportional to the integral of the power modulating function.

It is evident that we can restore the original modulating function by simply differentiating the pyroelectric output after it has been amplified.

The simplified detection scheme is shown in Fig. 1.

The high impedance amplifier consists of an open grid half-section 12AX7-A tube which is resistance coupled to the second half. The second half of the tube is a cathode follower designed for an output impedance of 200 ohms. The input resistance of the input amplifier appears to be on the order of 10^9 ohms and the parallel capacitance is on the order of 2 picofarads at the crystal electrodes.

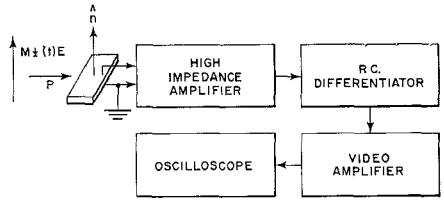

Fig. 1. Block diagram of detection scheme.

The video signal is differentiated at the 200-ohm level with an RC differentiator. A Kane Engineering Labs., Model C-4A video amplifier follows the differentiator. The pulse signal is observed on an H.P. 185B sampling oscilloscope.

It should be emphasized that the response time of the crystal and the input amplifier's RC time constant is not altered, i.e., for a carrier pulse signal the output of the two stage amplifier is a very linear asymmetrical triangular wave; after differentiation, the triangular wave is formed into a video pulse which is a degradation of the original carrier pulse envelope.

In this manner the sensitivity of the crystal is not disturbed as it is not appreciably loaded. However, some degradation of the signal plus noise to noise ratio is noted due to the nature of the RC differentiator.

The experiments are currently being conducted quasi-optically at room temperature in the 12.5- and 4-millimeter wavelengths. The characteristics of the detector appear to be roughly the same at either frequency. Since the optical coupling to the crystal is at present far from optimum, the maximum sensitivity of the detector is not known. However, sensitivities on the order of 10-microwatts peak source radiated power of a 10-microsecond carrier pulse (rise and decay time of 40 nanoseconds) with a signal plus noise to noise ratio of one dB are presently being recorded.

There are overtones which suggest that the sensitivity of the detector should increase with frequency (3); namely, the penetration depth of the wave decreases for constant dielectric properties. It can also be surmised that due to the low thermal conductivity of the ferroelectrics there exists a thermal gradient along the propagation axis at millimeter frequencies.

The validity of these statements are inconclusive since the dielectric properties of the ferroelectrics in the millimeter and submillimeter regions are not well enough known.

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Manuscript received August 23, 1965; revised October 11, 1965.

[1] In this instance, the active mass (m') can be defined in terms of an effective active volume, i.e., $m' = \rho V'$, where ρ is the density of the crystal. The effective volume can be defined as follows: assume that a plane wave is incident upon a rectangular ferroelectric crystal and oriented to the plane of the spontaneous polarization. The portion of the wave that is transmitted into the crystal is absorbed exponentially with distance due to its finite loss tangent. Define now a depth into the crystal (Z') where $\exp(-2\alpha Z') = 0.01$ and α is the attenuation coefficient. (This is indicative of 99 percent absorption of the wave.) Given a rectangular crystal, the active mass can be defined as

$$m' = \rho\tau l Z',$$

where τ is its thickness and l is its width.