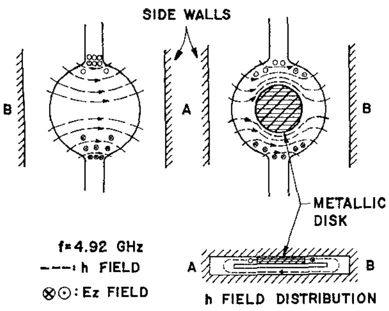

Fig. 4. Field patterns of the mode of interest for circulation.

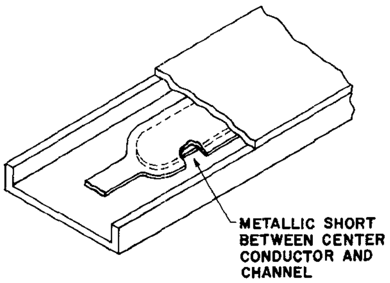

Fig. 5. Folded waveguide structure with strip-line input.

solution to the folded waveguiding structure shown in Fig. 5. The dominant mode in this structure has a TE_{10} like pattern which is folded back on itself at both sides of the waveguide. Some of the characteristics of this waveguide are the following: 1) Because of the reduced aspect ratio, the waveguide is low impedance. 2) The cutoff frequency is considerably reduced compared to a standard waveguide of similar external dimensions. 3) It is relatively simple to match into this waveguide from in-line coax or strip line. In addition to being useful for circulator design, this field configuration permits the design of broadband waveguide-type components with simple in-line coaxial terminals.

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On Nonresonant Perturbation Measurements

A perturbation measurement technique has been developed at Stanford University which determines the phase and field strength at a point inside a microwave structure by measuring the reflection produced at the input port by a perturbing bead. The theoretical basis for the measurement is presented in this issue by C. Steele [1]. Some applications and experimental considerations of the technique are presented here.

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A typical experimental setup is shown schematically in Fig. 1. Since the quantity of interest is the change of reflection due to the perturbation, the slide-screw tuner is used to tune out reflections before inserting the bead. The difference of the crystal currents is proportional to $A^2|\Gamma|\cos\phi$, where A is the amplitude of the reference signal from the generator, Γ is the reflection of the bead and ϕ is its phase. The phase of Γ for each bead location is determined by setting the precision phase shifter to achieve a null signal and the reflection amplitude by measuring the maximum unbalance signal. For a dielectric bead, Steele shows that $\Gamma = k\, E^2 \exp(2i\theta)/P_i$ where E and θ are the amplitude and the phase of the electric field at the bead and P_i is the input power. While the constant k is calculable for simple solids of revolution, it is often more convenient to calibrate a bead in a structure of known properties such as the uniform input waveguide to the test structure or a cavity consisting of a right circular cylinder.

As with any perturbation measurement, the perturbation must be small. The magnitude of the reflection coefficient must be much less than unity and the product of the the symmetry properties of the couplers for the SLAC accelerator sections. Although the accelerator section itself has cylindrical symmetry, the power is fed into the coupler from a waveguide iris on one side. An electron passing through an accelerator section is given a transverse impulse proportional to the line integral along the electron path of the quantity $j\partial E_z/\partial x$, where the complex quantity E_z is the coupler field. The measurement of the phase was made by R. P. Borghi and G. A. Loew with a precision of about 0.1° using the technique described before. A transverse phase shift of about 1° was observed, which was large enough to require design changes in the SLAC accelerator [2].

In waveguide two-ports, an additional useful measurement may be made. The perturbing bead may be represented as a shunt susceptance which introduces equal forward- and back-scattered waves in a running wave. The back-scattered wave is observed at the input; as shown by Steele, it is a measure of the square of the field, normalized to the input power. The forward-scattered wave is observed as a phase shift at the output; it is a measure of the square

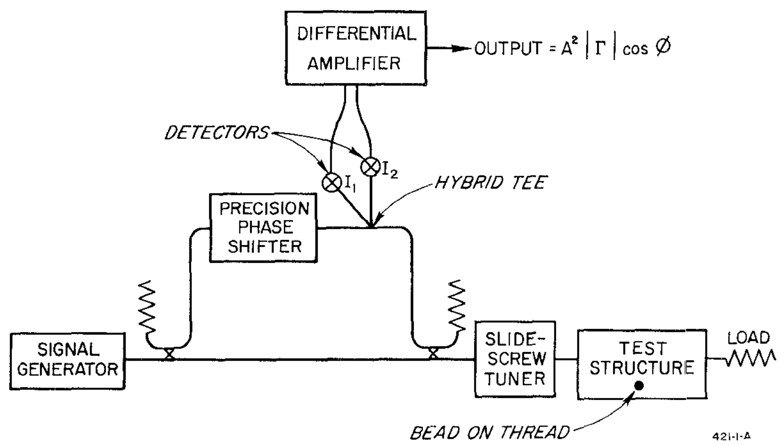

Fig. 1. Reflection perturbation measurement.

propagation constant associated with any coordinate by the length of the bead along that coordinate must be much less than unity (i.e., the bead must be much smaller than a wavelength). Furthermore, to avoid image effects, the distance from the walls of the structure to the bead must be large compared with the bead dimensions.

The technique is most useful in traveling-wave structure in which either 1) the structure is sufficiently irregular that the standing-wave pattern produced by resonating the structure masks the significant phase and field strength distributions, or 2) the loss is so high that the structure will not support a resonance of high Q-factor, well-separated from adjacent resonances.

One example of the first type was the measurement of fields in a high-power waveguide vacuum valve developed at Stanford Linear Accelerator Center. The technique was used by R. P. Borghi to measure the peak fields in the valve, thus determining the high power-handling capability.

Another example is the measurement of of the field intensity, normalized to the power flux at the bead [3], [4]. The ratio of the two is a measure of the attenuation from the input port to the bead.

The reflection and the transmitted phase-shift techniques were used by the authors to calibrate a mockup of the tapered disk-loaded bunching section of an X-band electron linear accelerator buncher.[1]

Measurement of the reflection from a perturbing bead allowed direct determination of the phase velocity and field strength on the axis of the structure. The ratio to the measurement of transmitted phase shift allowed a check of the predicted value of attenuation. Errors of phase velocity, field strength, and internal matching were disclosed in the calibration measurements of the mockup. Small corrections were computed and the final accelerator was constructed and remeasured.

[1] The phase velocity was to vary from 0.5 c to 1.0 c in the first five wavelengths of the structure. The field strength was to increase by a factor of 7 in the same distance.

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,

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$$\frac{\partial T}{\partial t} = \frac{1}{m' C_p J_1} \frac{\partial H(t)}{\partial t}, \tag{2}$$

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

$$\bar{J} = \frac{\partial \bar{P}_s}{\partial T} \frac{P(t)}{m' C_p J_1}. \tag{3}$$

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,

$$V_p(t) = \hat{n} \cdot \frac{\partial \bar{P}_s}{\partial T} \frac{\tau}{\epsilon_p m' C_p J_1} \int P(t) dt, \tag{6}$$

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

[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.

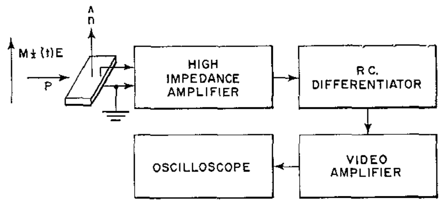

Fig. 1. Block diagram of detection scheme.

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.

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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