IV-6. A High-Power Ferroelectric Limiter

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A new type of solid state high-power limiter, which utilizes the large-signal nonlinear characteristics of ferroelectric materials, has been developed. Experimental 218 Mc units have handled peak input power levels in excess of 25 kw while yielding saturated output power levels of about 300 watts and a small-signal insertion loss of 0.5 db. The limiter consists of a symmetrical, loop-coupled, capacity-loaded, coaxial line cavity as shown in Fig. 1. A large portion of the capacity loading is provided by the ferroelectric pellet. Due to the large amount of capacitive loading yielded by the very high dielectric constant ferroelectric material, the cavity length is well under a quarter wavelength. An electric heater is located outside the cavity, but near the ferroelectric pellet, in order to bring the pellet temperature within a few degrees of its Curie temperature. Figure 1 also contains an expanded drawing of the region near the ferroelectric pellet. The power handling capability, saturated power output level, and small-signal insertion loss are determined by the radius (r_f) and height (d_f) of the ferroelectric pellet. High-voltage breakdown in this region is retarded by coating the lateral surfaces of the ferroelectric pellet and its supporting brass posts with corona dope. The entire assembly is also filled with sulfur hexafluoride gas (SF_6) as a further precaution against high-voltage breakdown.

The ferroelectric material used was a ceramic mixture of 45% lead titanate and 55% strontium titanate. This mixture is referred to in mole per cent. The small-signal dielectric constant (K) and dielectric loss tangent of this material were measured as a function of temperature (T). Figure 2 shows the results of these measurements made on a ferroelectric pellet terminating a coaxial transmission line. The temperature at which the dielectric constant reaches its maximum value, the Curie temperature (T_c), is 115.75°C for this particular ceramic mixture.

The dielectric constant curve is quite accurate, as these readings depend primarily on the location of a VSWR minimum. Since the VSWR's were very high, the minimums were located very accurately. The loss tangent curve is considerably less accurate, since the values of loss tangent depend primarily on the magnitude of the VSWR relative to the magnitude of the VSWR produced by a short circuit. The loss tangent is low enough to require the use of a cavity technique to obtain accurate data.

At low power levels, the limiter structure acts as a low insertion loss transmission cavity tuned to the signal frequency. As the power level increases, the high rf electric fields (E_{RF}) developed within the cavity cause the dielectric constant of the ferroelectric pellet to change, thus detuning the cavity. The detuned cavity causes most of the incoming power to be reflected at the input port. Similar reflections at the output port result in increased dissipative losses within the cavity.

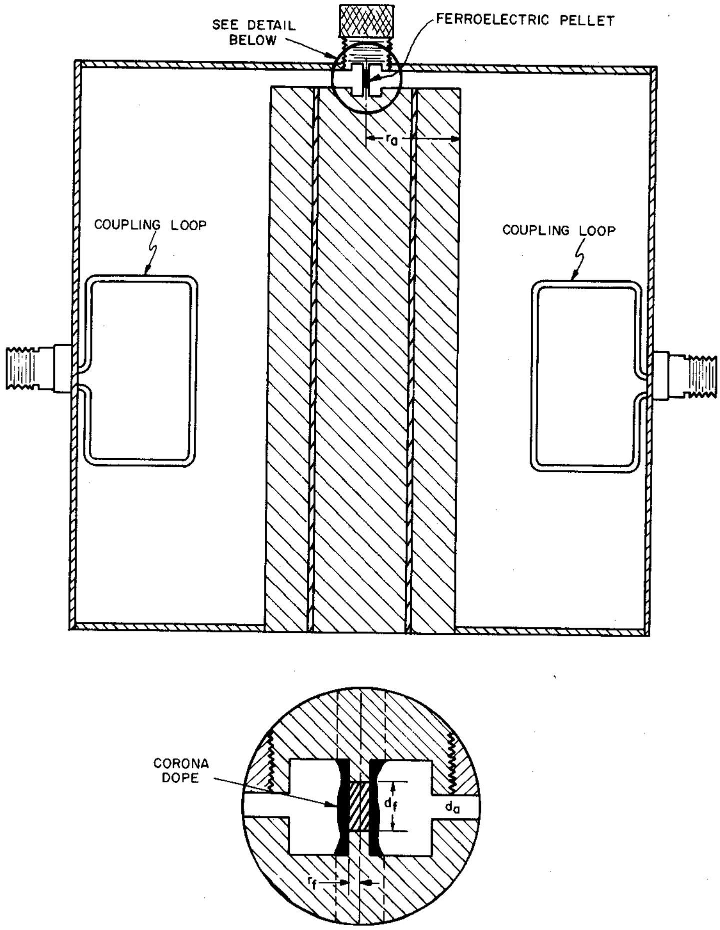

Fig. 1 Ferroelectric limiter configuration.

A theoretical analysis of the ferroelectric limiter shows that the performance of these devices can be controlled by adjusting the geometry in the vicinity of the ferroelectric pellet, and also adjusting the coupling coefficients of the cavity. Power-handling capabilities of hundreds of kilowatts are feasible. Figure 3 shows the small-signal frequency response of the cavity. Each of these curves is for a different coupling loop size and hence a different coupling coefficient. These measurements provide information on the coupling-loop configurations needed to obtain the desired values of small-signal insertion loss and loaded Q. These measurements have also shown that the small-signal loss tangent is less than .005.

Figure 4 shows the measured and theoretically predicted characteristics of the ferroelectric limiter for input power levels up to 26.3 kw. Small-signal measurements on this limiter showed an insertion loss of 0.85 db and a loaded Q of 47.5. In order to reduce the low-level insertion loss and increase the power-handling capability by decreasing the internal rf electric field, the coupling coefficient was increased. The low-level insertion loss was thereby decreased to 0.5 db and the loaded Q reduced to 28.3. The measured P_{out} vs P_{in} curve of this limiter is shown in Fig. 5. The observed P_{out} vs P_{in} characteristic of the limiter can be explained if the permittivity of the ferroelectric material (e_f) has the following dependence on the rf electric field intensity (E_{RF}):

$$e_f = e_0 (K - K_1 E_{RF})$$

K is determined from small-signal dielectric constant measurements and K_1 is determined from the saturation output power level. Measurements made on

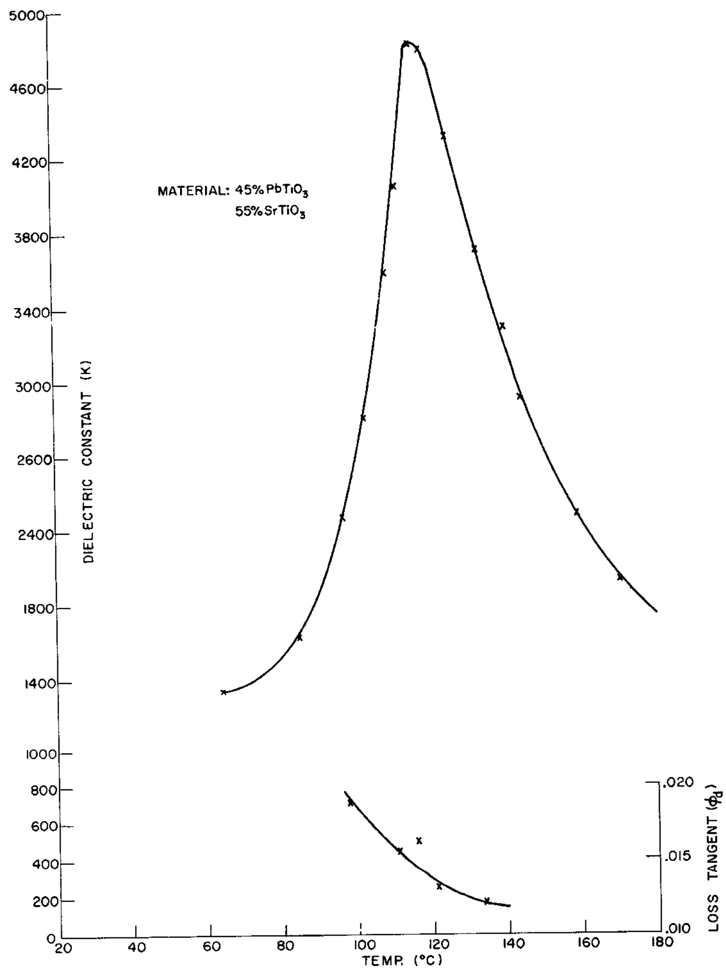

Fig. 2 Loss tangent and dielectric constant vs temperature.

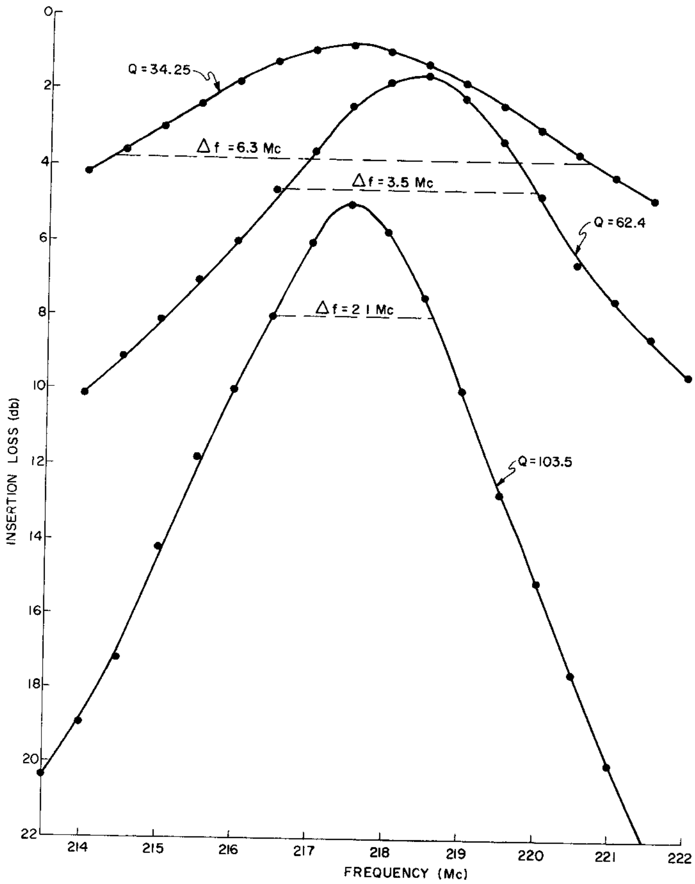

Fig. 3 Frequency response of ferroelectric loaded cavity.

two different ferroelectric pellets have yielded values of $K_1 = 2.0 \times 10^{-4}$ and 3.8×10^{-4} meters per volt. Additional data on the large-signal properties of ferroelectric materials is needed. The theoretical and measured curves shown in Figs. 4 and 5 are in excellent agreement.

An important operational characteristic of a limiter is its recovery time. To achieve rapid recovery, it is essential that the cavity detuning be due to the high electric field intensity rather than a temperature rise within the ferroelectric pellet. A theoretical analysis showed that the ferroelectric pellet temperature changes very little during an interval of a few milliseconds following cessation of the high power pulse. Recovery time measurements were made on the limiter. A train of alternate high and low-power pulses was supplied to the limiter input terminals. Oscilloscope photographs showed that the low-power pulse was visible within the trailing edge of the high-power pulse; in the case of the pulse width used in these measurements, this indicated a recovery time of less than 10 microseconds.

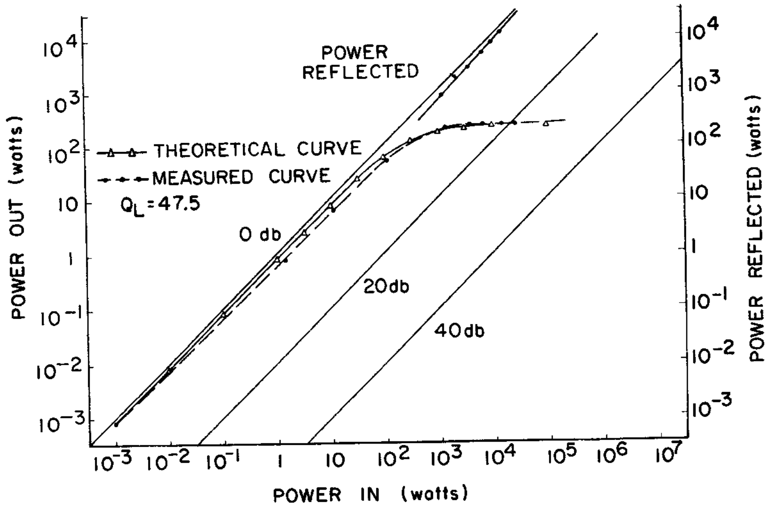

Fig. 4 Ferroelectric limiter characteristics.

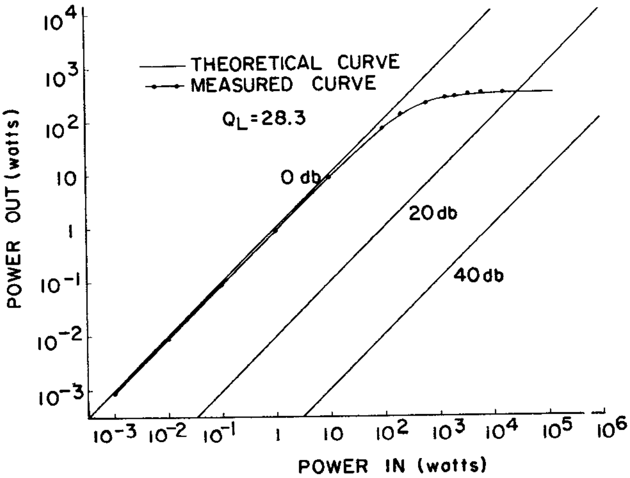

Fig. 5 Ferroelectric limiter characteristics.

ACKNOWLEDGMENT

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