A CALORIMETER FOR POWER MEASUREMENTS AT MILLIMETER WAVELENGTHS

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Abstract

A calorimeter for measuring low-level power at millimeter wavelengths is described. This is a broadband device capable of measuring power levels of the order of one milliwatt with an estimated accuracy of plus or minus 1/4 db. The calorimeter utilizes the substitution principle by matching the temperature rises of two identical power absorbers, in one of which is dissipated the unknown high frequency power while the other is heated by a measured amount of direct current power.

Introduction

Power measurements on an absolute basis are essential to the exploitation of a new frequency band (such as the millimeter wave band) since they are required for the determination of such quantities as: receiver noise figure, conversion loss of crystal first detectors, power output of oscillators and the efficiency of crystal harmonic producers.

This paper describes a calorimeter designed for measuring low level power in the millimeter wave band. With this instrument it is possible to measure powers of the order of one milliwatt in the wavelength range between 5 and 7 millimeters, corresponding to frequencies of about 60,000 and 43,000 megacycles. The estimated accuracy of the measurements is plus or minus 1/4 db. There is no obvious reason why this instrument could not be used for absolute power measurements at considerably shorter wavelengths.

Description of Calorimeter

The calorimeter utilizes the substitution principle by matching the temperature rises of two identical power absorbers, in one of which is dissipated the unknown high-frequency power while the other is heated by a measured amount of direct current power.

Figure I shows a sectional view of one of the absorbing terminations. It consists of a short section of thin walled round silver waveguide, 1/4 inch in diameter, containing a cast conical taper of absorbing material.[1] The mass of the termination is about one gram. The conical taper and the absorbing material are proportioned in such a way that a good termination is provided for the incoming high frequency wave which is completely dissipated in the termination as heat. DC power can also be fed through the termination from the outer shell through a small deposited silver band, located at the front end of the termination, to a circular contact located at the rear of the termination. A thin sheet of mica entirely encircles the outside of the remaining portions of the termination and prevents DC contact at any but the desired location. By proportioning the size of the silver band around the input to the termination, the DC and the high frequency power distributions may be made the same.

The temperature rise of the termination is indicated by the change in the resistance of a series string of three Western Electric 23A thermistor beads in intimate contact with the exterior of the thin-walled silver tube containing the lossy ceramic. These strings of thermistor beads, especially selected for similarity, are located at the front portion of the terminations and form two arms of a bridge network as shown in Figure II. On the left is shown the round waveguide sections through which the millimeter wave power is introduced into the conical tapered termination. Small spaces are provided between the waveguide sections to reduce conduction heat losses while polyfoam "stoppers" are placed inside each guide to prevent heat losses by convection. Since the two power absorbers are identical, either may be used to absorb the high frequency power while the other is supplied with DC power.

In order that the measuring signal power for the bridge be low, a pulsed signal is used as a means of detecting balance in the bridge. This signal is a low-powered, four microsecond trigger pulse obtained from a laboratory cathode-ray oscilloscope. The repetition rate used is 300 pulses per second which results in each thermistor bead receiving less than one microwatt of pulse power. Since high frequencies are involved in the pulsed signal, it is necessary that the bridge allow for both inductive and capacitive balancing, in addition to the usual resistive controls. Sufficient gain is introduced between the bridge and the cathode-ray oscillograph displaying the output so that operations near the noise level are possible. The maximum sensitivity of the system is obtained under these conditions.

Figure III is a photograph looking down on the calorimeter with its insulating covers removed. The outermost thermal barrier is a one-foot cube of one-half inch thick plywood which has been coated with aluminum paint. The smaller inner box is a seven inch cube, which is made of

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[1] Terminations are cast from a 50-50 mixture of "Conductoplast" and "Resistoplast" as supplied by The Atlas Mineral Products Company, Mertztown, Pa.

highly polished silver-plated brass. Inside this inner box, on the right, are located two 3 x 5 x 7 inch polyfoam blocks, which are covered with polished copper foil. At the center of each of these blocks is located one of the high-frequency wave guide terminations which are fed from the guides shown entering the calorimeter from the right. On the left are shown the elements necessary for the bridge network used in the measurement. The space between the inner and outer boxes is filled with a light-weight dry insulation of the rock wool type. Inasmuch as it was required that this calorimeter should be capable of measuring low-level powers of the order of one milliwatt to an accuracy of a fraction of a decibel, it was evident from the start that an extremely good job of thermal insulation would need to be done if a successful instrument were to result. With this in mind, every precaution was taken to provide the necessary radiation shields and insulation needed to minimize thermal losses.

Method of Operation

The actual measurement of high frequency power with the calorimeter is accomplished in the following manner. The bridge is first brought to balance in the standby condition with no power flowing in either of the terminations. This null condition is indicated on the output cathode-ray oscillograph by the base line with no pulse showing. The high frequency power to be measured is then introduced into one of the waveguide terminations, causing a temperature rise which changes the resistance of the associated thermistor beads. This, in turn, unbalances the bridge and a pulse signal appears on the output. This pulse may be either positive or negative, depending on which one of the terminations is heated. If now we feed an equal amount of DC power into the other termination, the bridge may again be balanced. Too little or too much DC power is indicated by a positive or negative pulse on the output, and the exact DC equivalent of the high frequency power will be indicated by a null. The time required to accomplish this balance adjustment is usually only a matter of a minute or two, but the steadiness of the balance may, if desired, be observed for a longer period of time. The measurement of the high frequency power thus becomes a matter of a DC power measurement and precision DC instruments must be employed for this measurement to obtain good accuracy.

Power measurements on an earlier model of this calorimeter built for operation at K-band (12.5 millimeters) were compared directly with measurements made with a K-band bolometer type of power measuring device. For these comparisons, the calorimeter was used with one termination in a standby condition and the DC or high frequency power was fed into the other termination. Curves of the type shown in Figure IV were obtained. These curves, the sectioned areas of which show the variation observed on repeated runs, indicate that differences in power of the order of 1/2 db in the one milliwatt region, curves "A", "B" and "C" are easily measurable. It can be seen that the high frequency curve "D" has the same shape as the DC curves, which indicates that the power distribution in the absorbing terminations is very nearly the same for the two cases. Curve "D" also shows that the calorimeter measures the power to be about 1/4 db greater than indicated by the bolometer. This difference is in the direction one would expect from a consideration of the possible errors in the bolometer measurement.

From measurements of the type shown on Figure IV, it is concluded that the accuracy of the calorimetric measurement of power at the one milliwatt level is better than ± 1/4 db. Actually, the accuracy of the 5 to 7 millimeter model, which was built later, should be better still since the masses of the power absorbers were considerably reduced for the higher frequency model with the result that the millimeter wave calorimeter is about three times faster than its K-band counterpart.

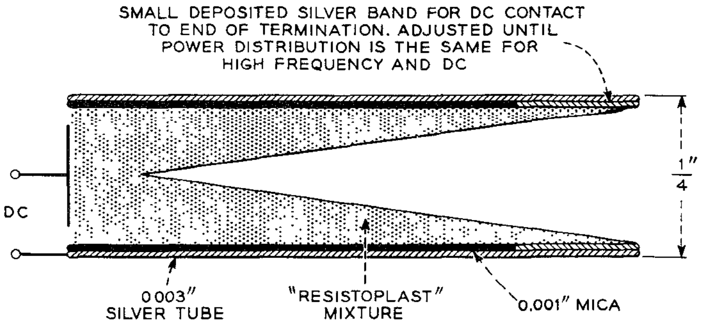

FIG. I - SECTION OF A ROUND GUIDE POWER ABSORBER FOR THE 5 TO 6 MILLIMETER CALORIMETER.

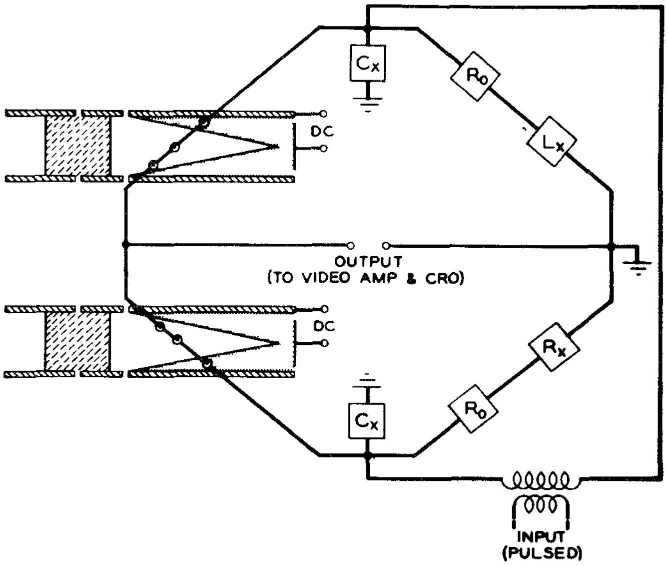

FIG. II - CALORIMETER BRIDGE NETWORK FOR USE AT MILLIMETER WAVES.

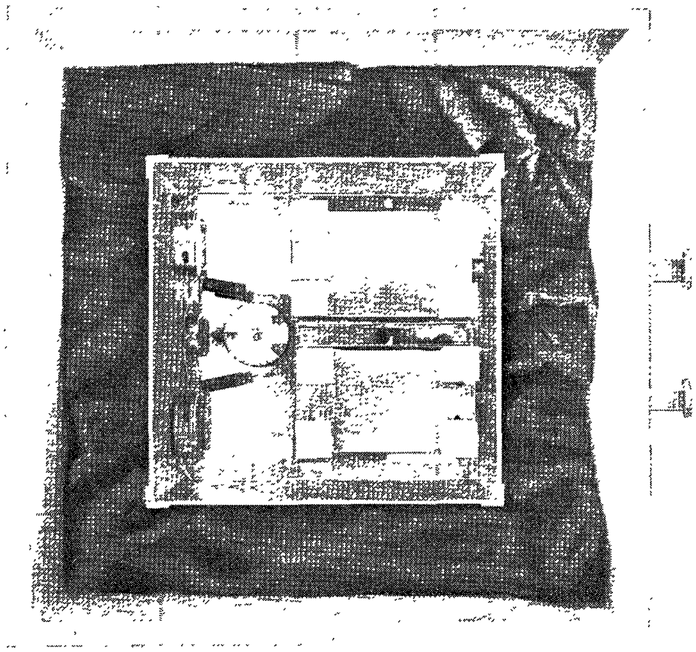

Fig. III - Millimeter-wave calorimeter with insulating covers removed.

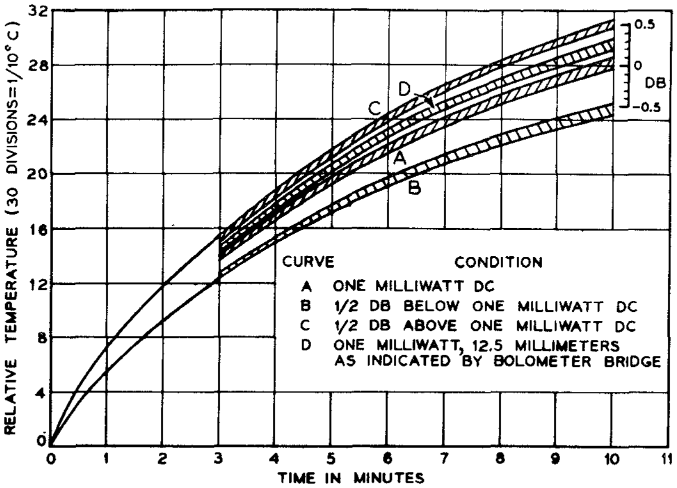

FIG. IV - TEMPERATURE RISE TIME CURVES FOR 12.5 MILLIMETER CALORIMETER.