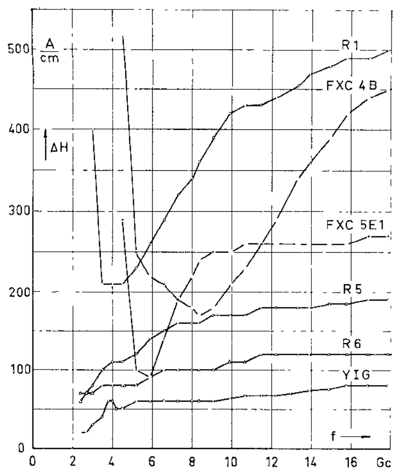

Fig. 1. Linewidth ΔH vs. frequency of polycrystalline spheres, 1-mm diameter.

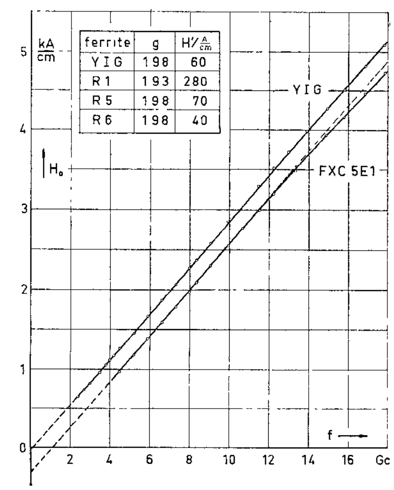

Fig. 2. Resonance field H_0 vs. frequency for FXC5E1 and YIG.

well-known form suggested by Okamura, et al. [5], the g-factor can be regarded as a value independant of frequency. Measurements at the R-ferrites and YIG have proved this statement. The g-factors of these materials are tabulated in Fig. 2 as well as the additional field H' introduced by Okamura, et al. The resonance behavior of FXC5E1 at room temperature, however, seems to be anomalous at frequencies above 12 Gc/s as can be seen from the diagram Fig. 2which gives a plot of the resonance field vs. frequency of this ferrite and, comparatively, that of YIG. An explanation of this behavior which has already been observed [4], [6] on FXC4B and other ferrites can not be given.

Acknowledgments

We wish to thank Prof. H. Doering for his continued interest in this work and for many valuable comments.

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International Intercomparison of Standards for Microwave Power Measurement

In accordance with a resolution of Commission I of the International Scientific Radio Union (URSI), standards for microwave power measurement of Japan, the United Kingdom (England) and the United States have been intercompared. It is the purpose of this correspondence to describe the results and comment upon the significance of these intercomparisons.

The interest of URSI in microwave power measurements extends back to the VIIth General Assembly which was held in Paris in 1946, and the resolution recommending the intercomparison of microwave power measuring techniques, which originated at that meeting, has been reaffirmed by each succeeding General Assembly. The potential usefulness of intercomparisons between the Primary Standards Laboratories of various countries was thus recognized well over a decade ago. It has only been in the past few years, however, that this resolution has been implemented.

Although the United Kingdom had, at an earlier date, affirmed its readiness and willingness to participate in such intercomparisons, to the Japanese National Committee also goes a large measure of credit for initiating this program when their delegates to the XIIth General Assembly (Boulder, Colorado, 1957) brought with them a calibrated bolometer mount and requested that it be compared with similar standards at the National Bureau of Standards, Boulder Laboratories (which were then in an advanced stage of development).

From this beginning, a total of five intercomparisons have been completed between Japan and the United States, two between Japan and the United Kingdom, and two between the United States and the United Kingdom. In each case the transfer standard employed has been a calibrated bolometer mount. For the purpose of reporting, the material may be conveniently divided into two sections:

1) Intercomparisons between Japan and the United States; and
2) The United Kingdom/Japan, United Kingdom/United States intercomparisons.

The details follow.

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Comparisons between Japan and the U. S.

The microwave power measurement techniques employed by both Japan and the United States are based upon refinements [1], [2] in the original work of Macpherson and Kerns [3]. The essential features of this technique include a microcalorimeter which is so devised as to permit a simultaneous calorimetric and bolometric determination of the power dissipated in a waveguide bolometer mount. The difference between the two measurements is attributed to the dc-RF substitution error and to power dissipation in the bolometer mount other than in the bolometer element (mount inefficiency). These two effects encompass the major sources of systematic error associated with the bolometric technique. In this way an effective efficiency (η_e) is obtained and employed in subsequent bolometric measurements. The bolometer mount may then be employed to determine the effective efficiency of other bolometer mounts by using well-known techniques [4]–[6].

In a number of these intercomparisons the bolometer mounts were also evaluated by the Kerns impedance method [7]. This procedure yields only the *efficiency* (η) of the bolometer mount in contrast with the *effective efficiency* (combined effect of efficiency and substitution error) as determined by the microcalorimetric method. Experience to date would tend to suggest, however, that the substitution error is much the less important of the two errors, at least at frequencies of 10 GH_z and lower. In addition the impedance method requires rather complex instrumentation and exacting attendant procedures, and is based upon a postulate whose validity is difficult to satisfactorily establish. For these reasons a somewhat greater level of confidence is assigned to the calorimetric determinations, although the results of these intercomparisons would appear to imply that a high order of accuracy is also possible with the impedance method. The procedure employed in Japan was based on a modification of the Beatty-Reggia [8] version, whereas in the United States a more recently developed [9] variation of the technique is now in use.

The first intercomparison was effected by means of a bolometer mount provided by Japan and designated J9-1. The results were as follows:

J9-1

Japan	United States
July 1957 $\eta_e=96.52\pm0.5\%$ $\eta=96.03\pm2\%$ January 1958 $\eta_e=09.36\pm1.9\%$ $\eta=90.01\pm2\%$	December 1957 $\eta_e=90.6\pm0.8\%$

(η_e and η were determined by the microcalorimetric and impedance methods as already described). It will be noted that the original Japanese and National Bureau of Standards' values differed by a nominal six percent, while the second Japanese and National Bureau of Standards' values are in good agreement.

The cause of the original discrepancy was traced to corrosion associated with certain soldering operations employed in the construction of the mount and the relatively long time lapse between the two measurements. As a result of this experience, an improved fabrication procedure was devised which eliminated the need for these soldering materials.

A second mount J9-6 was sent to the National Bureau of Standards in June 1959 but the barretter element was found to be open-circuited upon arrival, which rendered further measurements impossible. As a result of this experience, the Japanese have adopted improved quality control procedures in the fabrication of the barretter element, and no further trouble of this nature has been experienced to date.

A third mount J9-8 prepared by Japan yielded the following results:

J9-8

Japan	United States
July 1959 $\eta_e = 98.38^{+0.6}_{-0.3}\%$ $\eta = 95.4 \pm 2\%$ May 1960 $\eta_e = 99.23^{+0.6}_{-0.3}\%$	August 1959 $\eta_e = 99.1 \pm 0.7\%$ October 1959 $\eta = 98.6 \pm 0.7\%$

and a fourth mount J9-9 yielded:

J9-9

Japan	United States
March 1960 $\eta_e = 98.73^{+0.6}_{-0.3}\%$ $\eta = 96.5 \pm 2\%$ May 1960 $\eta_e = 99.08^{+0.6}_{-0.3}\%$	April 1960 $\eta_e = 98.85 \pm 0.7\%$ $\eta = 98.75 \pm 0.7\%$

Finally, a pair of mounts (NBS nos. 19 and 20) prepared by the National Bureau of Standards yielded the following results:

NBS-19

United States	Japan
April 1960 $\eta_e = 98.12 \pm 0.2\%$ August 1960 $\eta_e = 98.40 \pm 0.2\%$	May 1960 $\eta_e = 98.34^{+0.6}_{-0.3}\%$

NBS-20

United States	Japan
April 1960 $\eta_e = 98.47 \pm 0.2\%$ August 1960 $\eta_e = 98.63 \pm 0.2\%$	May 1960 $\eta_e = 98.71^{+0.6}_{-0.3}\%$

Perhaps the most important observation to be made from this data is that, within the quoted limits of error, the Japanese and U.S.A. standards are in good agreement, at least for the measurements based upon the calorimetric technique. With reference to measurements based upon the impedance technique, it will be noted that whereas good agreement exists between the microcalorimetric and impedance determinations performed at the National Bureau of Standards, the Japanese determinations by the impedance method are typically several percent below the calorimetric values. In this connection, it should be pointed out that the recently developed version of the impedance method employed by National Bureau of Standards is of such a nature as to be more readily adaptable to the type (fixed impedance) of bolometer mounts employed in the intercomparison, and is less demanding in the performance requirements imposed upon the accessory instrumentation and attendant operating procedures.

It is of interest to note that, with one exception, the values obtained by the participating country fall between the "before" and "after" values obtained by the country preparing the bolometer mount. It may also be observed that, with the exception of the first mount, the effective efficiencies appear to have experienced a slight increase with the passage of time. Because the apparent changes are within the individually quoted limits of error, however, it is difficult to assess the significance, if any, of this latter observation.

United Kingdom/United States and United Kingdom/Japan Intercomparisons

The techniques employed by the D.S.I.R. Radio Research Station in the United Kingdom in these intercomparisons include a constant-flow water calorimeter, a force-operated wattmeter, and a film bolometer mount of special design. In the calorimeter, the microwave power is absorbed by water which flows in a glass tube across the waveguide interior, and the difference in temperature between the incident and emergent water is indicative of the power absorbed.

The force-operated wattmeter employs a double vane which is suspended by means of a quartz fiber. The passage of microwave energy produces a torque which tends to rotate the vane, and a restoring torque is transmitted to the vane via the quartz fiber by means of a torsion head. The torque is a linear function of power, and the power is thus given by an equation of the form $P = K\theta$ where θ is the angular displacement of the torsion head and K a constant whose value may be determined by suitable auxiliary experiments.

The thin film used as the dissipative element in the film bolometer mount is located in a plane perpendicular to the waveguide axis. Its dimensions are chosen in such a way that a good impedance match is achieved without the use of auxiliary tuning elements such as stubs, irises, etc. Each of the foregoing techniques has been described in detail in the literature [10]–[12].

In the existing state-of-the-art, the accuracy expectancy of these methods is somewhat less than that ascribed to the microcalorimetric measurements performed in Japan and in the United States. In addition, the participating laboratory in the United Kingdom has assumed the responsibility for providing the attenuator calibration required to bridge the nominal 30-dB gap between the milliwatt level at which the bolometric standards are used and the watt levels at which the water calorimeter and torque vane wattmeter operate. This represents another potential source of systematic error.

In spite of this, these intercomparisons in which the United Kingdom participated are more significant in their implications as to the absolute accuracy of the various techniques involved because of the wide differences in their basic operating principles. By contrast, when two closely related methods are compared, as was the case in the Japanese/United States intercomparisons, systematic errors are more likely to go undetected, and close agreement may be indicative only of the precision of the methods in contrast with absolute accuracy.

The methods employed in the United Kingdom were all of such a nature as to yield the effective efficiency as defined earlier. In a comparison utilizing a bolometer mount prepared by the United States the following results were obtained:

NBS-2

United States	United Kingdom
June 1958 $\eta_e = 98.50 \pm 0.2\%$ $\eta = 98.4 \pm 0.7\%$ October 1958 $\eta_e = 98.33 \pm 0.2\%$	August 1958 $\eta_e = 97.2 \pm 1.5\%$ (Flow calorimeter) $\eta_e = 97.8 \pm 1.5\%$ (Force-operated watt meter)

A more recent comparison was made by use of the National Bureau of Standards' bolometer mounts Nos. 19 and 20 which had been employed in an earlier comparison with Japan. This provided the following results:

NBS-19

United States	United Kingdom
August 1960 $\eta_e = 98.40 \pm 0.2\%$ January 1961 $\eta_e = 98.25 \pm 0.2\%$	November 1960 $\eta_e \pm 98.3 = \pm 1\%$ (Film bolometer)

NBS-20

United States	United Kingdom
August 1960 $\eta_e = 98.63 \pm 0.2\%$ January 1961 $\eta_e = 98.71 \pm 0.2\%$	November 1960 $\eta_e = 98.1 \pm 1\%$ (Film bolometer)

Two comparisons have been completed between Japan and the United Kingdom, by means of bolometer mounts prepared by Japan. In the first of these, using the mount J9-7, the results were:

J9-7

JAPAN	UNITED KINGDOM
March 1959 $\eta_e=98.65^{+0.6}_{-0.3}\%$	
December 1959 $\eta=97.1\pm2\%$	July 1959 $\eta_e=96.6\pm1.5\%$ (Flow calorimeter)
May 1960 $\eta_e=99.5^{+0.6}_{-0.3}\%$	

and for the second mount, J9-6:

J9-6

JAPAN	UNITED KINGDOM
March 1960 $\eta_e=99.13^{+0.6}_{-0.3}\%$	May 1960 $\eta_e=98.2\pm1\%$ (Film bolometer)
$\eta=96.54\pm2\%$	

Once again, within the individually estimated limits of error, the values are essentially in agreement. This is obviously an important result, particularly in view of the basic differences in operating principles of the techniques employed.

It will be further noted, however, that most of the results obtained in the United Kingdom are of the order of one percent below the United States or Japanese results. Even though this difference is within the quoted limits of error, its consistent nature suggests the presence of a systematic error.

An exception to this general behavior is found in the results of the most recent U. S.—U. K. comparison. The reference standard employed by the United Kingdom was, in this case, the film bolometer.

A spokesman for the United Kingdom has indicated that the milliwatt power levels from their flow calorimeter or force-operated wattmeter may, in fact, be a nominal one percent below the correct value. Such an error might be inherent in these high-level power meters or, alternatively, may have been introduced in the calibration of the directional coupler used to provide the nominal 35 dB of attenuation required in comparing the high and low power standards. Further intercomparisons are planned between the United Kingdom and the United States in an effort to resolve this question.

In summary, a number of useful benefits have resulted from this intercomparison program. Perhaps the most important single result is the confidence and reassurance which stems from the close agreement achieved in the intercomparisons.

The secondary benefits include,

For Japan: An improved bolometer mount design has emerged from the correction of certain inherent weaknesses which were discovered as a result of the intercomparison process. The intercomparisons have also called attention to the fact that the agreement achieved between their impedance and calorimetric determinations could probably be improved, perhaps by adopting a technique similar to that employed at the National Bureau of Standards.

For the United Kingdom: This program has suggested the possible existence of a systematic error, possibly as large as one percent, in their measurement system. In addition, their representatives have expressed a great deal of interest in the high efficiencies achieved by the bolometer mounts of Japanese and United States design and in the close agreement achieved by the calorimetric and impedance methods in the United States.

For the United States: The benefits are perhaps a bit less tangible than those already listed; however, a sizeable amount of stimulus has been derived from, and confidence developed in our measurement techniques, as a result of participating in this program.

Finally, the author is confident that he is expressing the sentiments of the representatives of Japan and the United Kingdom as well as those of the participating laboratory in the United States in extending the invitation for other interested countries to participate in these intercomparisons.

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Additional "Comment on Wave Propagation in Sinusoidally Stratified Dielectric Media"

ACKNOWLEDGMENT

In the above correspondence,[1] acknowledgment of a prior work was inadvertently omitted. The undersigned wishes to apologize for this unintentional oversight and to acknowledge the earlier work of Professors Yeh and Kaprielian[2] on wave propagation in a sinusoidally stratified dielectric. Also the point made by Professor Yeh should be emphasized, that the original intent of the correspondence was to present an alternative approach in the derivation of the Mathieu and Hill equations and, additionally, to call attention to the potential applications inherent in the use of such a dielectric medium. The significance and importance of the earlier work[2] were of such a degree as to be of interest to the microwave community in general and, in particular, to those interested in microwave acoustics and photon-phonon interaction. The possibilities for device development are being actively explored and, hopefully, results will be forthcoming in the near future.

Professors Yeh and Kaprielian are to be complimented for completing the work on the Hill equation and investigating the TM mode propagation. The work will, of course, complement the earlier discussion of Tamir, *et al.*,[3] which dealt with TE modes.

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Recent Changes in High-Frequency and Microwave Calibration Services

The following short items describe recent changes in the calibration services offered by the Radio Standards Laboratory at Boulder, Colo.[1]

The first three items are concerned with waveguide attenuation. Item I reports an extension of the frequency range of waveguide attenuation calibrations; Item II, an improvement in accuracy of measuring attenuation differences on variable attenuators; and Item III, an extension of reflection coefficient measurements to an additional waveguide size.

The remaining items relate to power-measuring devices. Item IV reports an extension in frequency range of calibration of RF calorimeters; Item V, an increase in range of power level for calibrations of X-band standards; and Item VI announces a change in the procedure for calibrating waveguide bolometer-coupler units.

I. WAVEGUIDE CALIBRATION CHANGES

The Radio Standards Laboratory has announced an extension of the attenuation

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[1] This laboratory is part of the Institute for Basic Standards of the National Bureau of Standards (U. S. Department of Commerce).