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.

G. F. ENGEN
Radio Standards Lab.
Boulder, Colo.

REFERENCES

[1] S. Omori and K. Sakuari, A new estimating method of equivalence error in the microwave microcalorimeter, *IRE Trans. on Instrumentation*, vol. I-7, pp. 307–309, December 1958.
[2] G. F. Engen, A refined X-band microwave microcalorimeter, *J. Res. NBS*, vol. 63 C, p. 77, July–September 1959.
[3] A. C. Macpherson and D. M. Kerns, A microwave microcalorimeter, *Rev. Sci., Instr.*, vol. 26, p. 27, January 1955.
[4] R. W. Beatty and A. C. Macpherson, Mismatch errors in microwave power measurements, *Proc. IRE*, vol 41, pp. 1112–1119, September 1953.
[5] G. F. Engen, Recent developments in the field of microwave power measurements at the National Bureau of Standards, *IRE Trans. on Instrumentation*, vol. I-7, pp. 304–306, December 1958.
[6] ——, A transfer instrument for the intercomparison of microwave power meters, *IRE Trans. on Instrumentation*, vol. I-9, pp. 202–208, September 1960.
[7] D. M. Kerns, Determination of efficiency of microwave bolometer mounts from impedance data, *J. Res. NBS*, vol. 42, p. 579, June 1959.
[8] R. W. Beatty and F. Reggia, An improved method of measuring efficicencies of ultra-high frequency and microwave bolometer mounts, *J. Res. NBS*, vol. 54, p. 321, June 1955.
[9] G. F. Engen, A bolometer mount efficiency measurement technique, *J. Res. NBS*, vol. 65C, p. 113, April–June 1961.
[10] J. A. Lane, The measurement of power at a wavelength of three cm by thermistors and bolometers, *Proc. IEE (London)*, vol. 102, pt. B, p. 819, November 1955.
[11] A. L. Cullen, B. Rogal, and S. Okamara, A wide-band double-vane torque-operated wattmeter for 3-cm microwaves, *IRE Trans. on Microwave Theory and Techniques*, vol. MTT-6, pp. 135–136, April 1958.
[12] J. A. Lane, Transverse film bolometers for the measurement of power in rectangular waveguides, *Proc. IEE (London)*, vol. 105, pt B, p. 77, January 1958.

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.

R. A. KALLAS
Motorola Inc.
Scottsdale, Ariz.

Manuscript received June 7, 1965.

[1] R. A. Kallas, *IEEE Trans. on Microwave Theory and Techniques (Correspondence)*, pp. 139–141, January 1965.

[2] C. H. Yeh and Z. A. Kaprielian, "On inhomogenerously filled waveguides," University of Southern California, Engineering Center Los Angeles, Calif., Rept. 84-206, November 1963.

[3] T. Tamir, H. C. Wang, and A. A. Oliner, "Wave propagation in sinusoidally stratified dielectric media," *IEEE Trans. on Microwave Theory and Techniques*, pp. 323–335, May 1964.

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

Manuscript received June 14, 1965.

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

calibration service to include WR 28-size waveguide (26.5–40.0 Gc/s). The service includes attenuation difference measurements on variable attenuators and insertion-loss measurements on fixed attenuators. This provides an attenuation calibration service over eight waveguide sizes, covering a frequency range from 2.60 to 40.0 Gc/s. Development work is in progress to extend the service in several waveguide sizes above and below the present limits to 2.6 and 40.0 Gc/s.

The Radio Standards Laboratory has discontinued the attenuation measurement of three-port and four-port waveguide directional couplers, accepting only two-port waveguide attenuators for calibration. For some years the Bureau has provided a calibration service for three-port and four-port waveguide directional couplers for use as highly stable fixed value attenuation standards. With the "in-line" type of precision fixed-waveguide attenuator becoming commercially available, the superior features of this type of attenuator make the use of the older directional coupler obsolete as a fixed attenuation standard.

II. Improved Attenuation Measurements at Microwave Frequencies

An improvement in accuracy for attenuation difference measurements on variable attenuators from 0.1 dB/10 dB to 0.05 dB/10 dB (0.5 percent of the attenuation in decibels) has been available for some time in WR 90 waveguide (8.2–12.4 Gc/s). More recently this increased accuracy has become available in four additional waveguide sizes:

WR 284 (2.6–3.95 Gc/s)
WR 187 (3.95–5.85 Gc/s)
WR 137 (5.85–8.2 Gc/s)
WR 62 (12.4–18.0 Gc/s).

An accuracy of 0.1 dB/10 dB (one percent of the attenuation in decibels) is reported for insertion-loss measurements of fixed attenuators.

This improvement in accuracy of the attenuation measurement leads to a corresponding improvement in the impedance match at the attenuator insertion points. Formerly the mismatch produced a VSWR of 1.05 or less, whereas it is possible now to hold the mismatch to a VSWR below 1.02.

III. Measurement of Waveguide Reflectors Extended to Additional Waveguide Size

Measurement of the reflection coefficient magnitude of waveguide reflectors (mismatches) in WR 62 waveguide (12.4–18.0 Gc/s) was announced by the Laboratory as a calibration service. The service was available previously in only one waveguide size, that of WR 90 (8.2–12.4 Gc/s).

Although measurement of the reflection coefficient magnitude can be made at any frequency over the range of 12.4 to 18.0 Gc/s, it should be emphasized that measurements are made at selected frequencies of 13.5, 15.0, and 17.0 Gc/s. This is done primarily for the economy and convenience of those requesting calibrations. Measurements can be made over a magnitude range of 0.025 to 1.0 with an uncertainty of plus or minus one percent. It is very essential that the flange be machined flat and smooth and be without protrusions or indentations.

IV. Calibration of RF Calorimeters Extended to 5000 Mc/s

The Radio Standards Laboratory announces that the calibration of coaxial-type RF calorimeters is now extended in frequency range to 500 Mc/s. Formerly the upper frequency limit was 400 Mc/s. Calibrations at CW power levels between 0.001 to 100 watts are made at the selected frequencies of 100, 200, 300, 400, and 500 Mc/s. Below 100 Mc/s measurements can be made at power levels extending up to 200 watts. Uncertainties in the measurements are expressed in the range of one to two percent, depending upon the stability and SWR of the calorimeter being calibrated.

V. X-Band Bolometric and Calorimetric Standards

With the availability of suitable traveling-wave tube amplifiers, it is now possible to obtain microwave energy at considerably higher power and with good stability and low noise. This source of CW microwave power is being utilized by the Radio Standards Laboratory to perform calibrations up to a power level of one watt on bolometric and calorimetric devices in the frequency range of 8.2 to 12.4 Gc/s (X-band). Formerly the power level was limited to 100 mw. Uncertainty in the measurements is expected to be no greater than one percent.

VI. Waveguide Bolometer-Coupler Units

The calibration of waveguide bolometer-coupler units[2] for use as power measurement devices at microwave frequencies requires a determination of Γ_g, the equivalent reflection coefficient looking into the output port of the coupler. Determination of the equivalent reflection coefficient by the Radio Standards Laboratory is made preferably with the bolometer unit detached from the coupler, though the determination can be made with the bolometer unit attached. It will be future practice, unless the Laboratory is specifically instructed otherwise, to separate the bolometer-coupler units to determine initially the equivalent reflection coefficient. Upon repeating a power calibration, if the measurement shows no marked change from the previous calibration, the determination of equivalent reflection coefficient will not be repeated. If there is a change in the power calibration, however, Γ_g will be redetermined with the bolometer-coupler unit intact to preserve the calibration history.

National Bureau of Standards
Engrg. Div.
Radio Standards Lab.
Boulder, Colo.

[2] See, "Extension of waveguide power calibration service," *NBS Tech. News Bull.*, vol. 47, p. 141, August 1963.

Propagation in Cylindrical Waveguide Containing Inhomogeneous Dielectric

The wave equations in the cylindrical waveguide containing inhomogeneous dielectric are[1]

$$\Delta \times \Delta \times E_T - \nabla \frac{1}{\epsilon} \nabla \cdot \epsilon E_T - (\gamma^2 + \omega^2 \epsilon \mu) E_T = 0 \quad (1)$$

$$\epsilon \nabla \times \frac{1}{\epsilon} \nabla \times H_T - \nabla \nabla \cdot H_T - (\gamma^2 + \omega^2 \epsilon \mu) H_T = 0. \quad (2)$$

These equations are solved here in two cases: 1) Rectangular waveguide wherein the dielectric constant varies linearly across the broad dimensions, 2) circular waveguide wherein the dielectric constant varies quadratically with the distance from the tube axis. The surface of the waveguide is assumed to be perfectly conductive.

I. Rectangular Waveguide

A. LSE-mode[2]

Putting $E_x = 0$, $E_y = \cos\ (m\pi y/2b) \cdot X$, $\epsilon = \epsilon_0(1 - px)$ in (1):

$$\frac{d^2 X}{dx^2} + (\gamma' - \epsilon' x) X = 0 \quad (3)$$

where $\gamma_i = \gamma^2 + \omega^2 \epsilon_0 \mu - (m\pi/2b),^2$ $\epsilon' = p\omega^2 \epsilon_0 \mu = (2\pi/\lambda_0)^2 (n_1 - n_2)/a$. n_1, n_2 are the refraction indexes at $x = 0$, $2a$, respectively. The solutions of (3) can be written in terms of Bessel function of order $\frac{1}{3}$, $-\frac{1}{3}$. The eigenvalues γ', which are determined by the boundary condition at $x = 0$, $2a$, $E_y = 0$, are calculated from

$$J_{1/3}(\zeta^{3/2}) / J_{-1/3}(\zeta^{3/2}) = J_{1/3}(\eta^{3/2}) / J_{-1/3}(\eta^{3/2}) \quad \text{if} \quad \gamma' - 2\epsilon' a > 0 \quad (4)$$

$$= -I_{1/3}((-\eta)^{3/2}) / I_{-1/3}(-\eta)^{3/2} \quad \text{if} \quad \gamma' - 2\epsilon' a < 0 \quad (4')$$

where

$$\zeta = (2/3\epsilon')^{2/3} \gamma', \quad \eta = (2/3\epsilon')^{2/3} (\gamma' - 2\epsilon' a).$$

The eigenvalues γ', evaluated by the use of asymptotic expansions of the Airy functions, are[3]

$$\gamma_n' \doteqdot (n\pi/2a)^2 + \epsilon' a \quad \text{if} \quad \epsilon' a \ll 1 \quad (5)$$

$$2\gamma_n'^{3/2}/3\epsilon' \doteqdot (n - 1/4)\pi \quad \text{if} \quad \epsilon' a > \gamma_n'. \quad (5')$$

B. LSM-mode

This mode can be obtained by the similar method as that of LSE-mode.

II. Circular Waveguide

In this case, the normal modes are in general combinations of TE and TM modes and are very complicated. Here calculations are made for circularly symmetrical modes (TE_{0n} and TM_{0n} modes).

C. TE_{0n} mode

Manuscript received April 7, 1965.

[1] R. B. Adler, "Waves on inhomogeneous cylindrical structure," *Proc. IRE*, vol. 40, pp. 339–348, March 1952.

[2] R. E. Collin, *Field Theory of Guided Waves*, New York: McGraw-Hill, 1960.

[3] D. E. Kerr, *Propagation of Short Radio Waves*, Rad. Lab. Ser. 13, New York: McGraw-Hill, 1951.