A CALIBRATION FACILITY FOR MICROWAVE MONITORS - DESIGN AND OPERATING EXPERIENCE

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(A broad-band microwave calibration facility has been designed and partly completed. Evaluation of the facility and its progressive design are described and calibration results presented).

Since 1963, the Australian Radiation Laboratory has taken an active interest in the hazards of microwave radiation, and has offered advice on request. Following a specific case of inadvertant entry of persons to an area close to a powerful transmitting radar antenna in 1966, a Narda Model B86B3 broadband monitor was purchased to permit measurements to be made in support of the calculations relied on to that date.

It was realised that the calibration of the available monitors was made at several frequencies only, that the variation of calibration factors from one frequency to another was quite large and that "holes" in the frequency response may well occur between calibration points. Thus the need for broad-band calibration was recognised at this early stage. Microwave ovens were subsequently introduced into Australia and Narda Models 8100 and 8200 near - field monitors were purchased in due course. Initial investigations soon revealed marked differences in response of identical probes, hence calibration was first undertaken at 2450 MHz. The system shown in Figure 1 was set up as a first step. At this time no calibration manual for the instruments described above was available from the manufacturer.

The microwave absorber used in this system is Plessey Type AF50 pyramidal absorber twelve inches thick and covering an area 8 feet by 8 feet. The facility was set up on a discontinuous basis in the centre of a large room with a ceiling 11 feet high and having a width of 14 feet. The nearest broad surfaces were thus approximately 13 wavelengths away from receiver and transmitter at 2450 MHz. The radiation source is a diathermy generator (with additional mains power filtering and stabilising circuits) which incorporates a magnetron to produce up to 120 watts of power. A large mismatch at the generator output was successfully tuned out using a two-stub turner. The circuit was set up using coaxial components because many components were not available in waveguide in LS-band and in order to facilitate extension to broad-band. The power measurement was made with a Hewlett Packard Model 432A thermistor meter and coaxial mount and the manufacturer's calibration was and is relied on as no microwave power or power density standard exists as yet in Australia. The antenna used is one of a pair of identical Narda LS-band standard gain horns which have been connected by cover flanges to Narda waveguide-to-coaxial adapters. A pair was purchased to undertake measurements of antenna gain, initially to reduce the uncertainty in the gain quoted by the manufacturer.

Power density at distance R was derived using

$$W_R = \frac{P_o\, G_R}{4\,\Pi R^2} \qquad (1)$$

where G_R = Gain of antenna at distance R from antenna

W_R = Power density at distance R from antenna

P_o = Output power at the antenna

P_o is known in terms of the power indicated on the meter

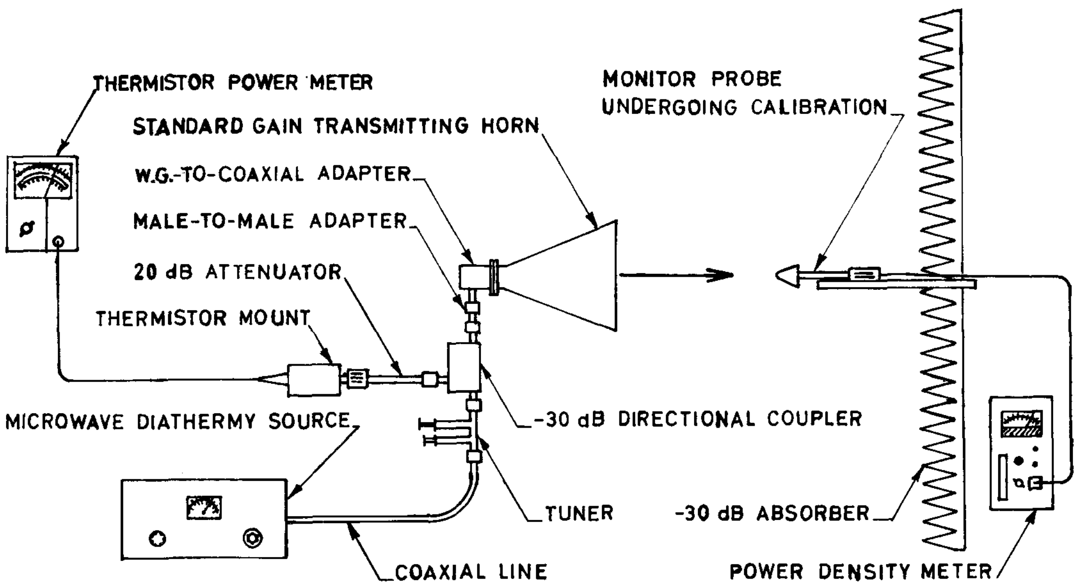

FIG.1 INITIAL SYSTEM FOR CALIBRATION OF MONITORS AT 2450 MHz

The initial calibrations were undertaken at an antenna separation of 3 metres although it was realised that side lobe and main beam reflections would be significant. Calculations show that for the antennas used, the usual far-field criterion of $2a^2$, taking a as the greatest distance between two points on the antenna aperture, is 3.09 metres at 2450 MHz. The total error in calibration could not be estimated as defects in the "anechoic enclosure" could not be determined, however, apart from this uncertainty the total uncertainty, after all possible corrections based on manufacturer's calibrations of components, was estimated to be + 16%, - 27%. This included an antenna gain uncertainty of ± 7% as given by the manufacturer. A significant part of the total uncertainty was due to conjugate mismatch losses calculated on the basis of manufacturer's specifications of V.S.W.R. The total actual error was thus thought likely to be much less than the maximum uncertainty calculated when tuned for maximum power transfer to the horn antenna.

The maximum reflection from the horn and adapters was calculated to be 7.4% but recent measurements using a dual directional coupler have shown only 0.4% of the forward power being reflected at 2450 MHz when mismatch has been tuned out. The effect of floor reflections has also been investigated with the use of additional absorber (Eastern Microwave Corp. Type FFP-8) recently purchased. This investigation showed received power density to be 2% lower at 3 metres when the floor was covered with absorber. However a 4% decrease was observed at 2 metres and a 4% increase at 96 inches, the calibration distance recommended by Narda for their Model 8100 probes.

An early calibration of a Model 8121 A probe at 3 metres gave a calibration factor of 1.19, corresponding to a response 16% below the expected value but within the limit of uncertainty. This was based on an antenna gain of 50 as given by the monitor manufacturer. In the calibration manual for the 8100 instrument, the manufacturer recommends the use of this gain figure at 2450 MHz at 96" from the front face of the horn. (The same manufacturer provided a gain calibration curve for the horn antennas which gives a gain of 50.13 at 2450 MHz, but it must be assumed that this is intended as a far-field gain as no distance is stated). This calibration was considered satisfactory but later the two horn antennas were used to obtain measurements of received power versus distance over the range 1 to 3 metres.

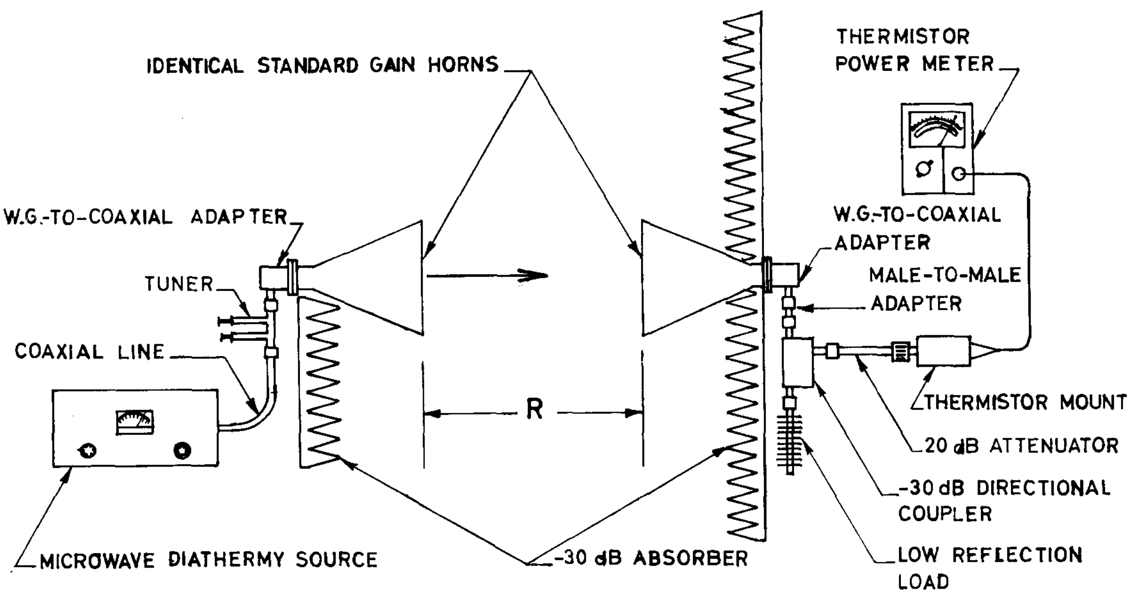

FIG.2 SYSTEM FOR MEASUREMENT OF GAIN OF IDENTICAL HORNS

The circuit shown in Fig. 2 was used. This circuit was acceptable because the microwave generator was shown in other measurements to be remarkably stable, linear and reproducible, especially if care was paid to tuning out the output mismatch. The gain was computed by the far-field power-transmission formula:

$$P_R/P_T = \left(\frac{\lambda G}{4\Pi R}\right)^2 \text{ where} \quad (2)$$

P_R = received power
P_T = transmitted power
G = directional gain of both horns
λ = wavelength
R = antenna separation

As P_T and λ were kept constant, formula (2) reduces to

$$P_R = \frac{k\ G^2}{R^2} \qquad (3)$$

$$\text{where} \quad k = \frac{P_T \lambda^2}{4\ \Pi} \qquad (4)$$

and if G is constant an inverse-square relationship will exist between P_R and R. G was expected to vary because of multiple coupling between the antennas and phase variation across the face of each horn. Computed values of G varied from 42.6 at 1 metre to 51.7 at 3 metres. The inverse-square relation between P_R and R did not hold but could be recovered by the method of Jakes[1] by adding a small distance d to R and iterating this procedure until an inverse square curve was obtained. The distance to be added was 32 centimetres, which does not correspond closely to twice the axial height of the horns (approximately 40 centimetres). These are not optimum horns, but the departure from the axial height is rather marked and may indicate errors due to the inadequacy of the "anechoic" enclosure. This was further emphasised when similar range tests using a Narda Model 8121A probe and a single horn required addition of d = 20 centimetres to produce an inverse square fit and constant G. Approximately one half of the value of d required for the two rectangular horns was expected. However, the gain computed at 96" was 50.6 which compares well with the gain figure of 50 recommended by the manufacturer in its model 8100 calibration manual. The inverse square fit corresponded to a far field (constant) gain of 57.4.

Recalculating the calibration factor for the initial calibration using the measured gain of 51.7, the response of the probe is 21% low, outside the manufacturer's limits and the uncertainty limit (when reduced by 7% to allow for mismatch removed by use of the tuner).

Although these investigations leave several questions unresolved with regard to absolute calibration, this early facility allowed accurate and useful comparisons of probes and monitors with valuable results. Also the high power of the microwave source allows power density linearity tests on all probes at reasonable separations from the transmitting antenna. These tests have shown all Narda probes for Models 8100 and 8200 to have closely linear response with zero intercept at zero transmitted power despite probe calibration corrections determined at 96" lying within the limits of + 48.7% and - 87.4%. The Narda Model B86B3 broadband monitors checked at 2450 MHz have responses which are fairly linear but have lines of best fit which have a positive intercept at zero power of 2 to 3 mw/cm^2. At 2 metres, responses of two of these monitors were 66% higher than the estimated value. The manufacturer's recommended distance for calibration is 47". The gain variation measured between 47" and 2 metres was from 45.4 to 49.7 and does not appear to be the source of calibration variation from the manufacturer's setting. The calibration system is presently undergoing refinement. Fig. 3 indicates the system presently assembled and under test in the band 1.7 to 2.6 GHz. The principle of this system is a swept frequency power source employing a solid state sweep oscillator and travelling-wave-tube amplifier. This system is stabilised and levelled on the difference signal between forward and reflected power. The effective V.S.W.R. of the source is expected to be low and at some frequencies extremely small reflected power is expected. However, the horn, adapter combination has been swept frequency analysed recently. The V.S.W.R. is markedly variable and rather large at some frequencies, hence the system is expected to provide a more linear output power as frequency is swept than a system based on forward levelling alone. The output will be frequency dependent nevertheless due to the frequency dependence of horn gain, but this will be low over narrow sweep bands and will be calibrated at single frequencies in the swept band.

Uncertainty of power measurement seems of minor significance in the total uncertainty but mismatch is of greater consequence due to frequency dependence of the components used in the system. Hence the methods proposed by Engen[2,3,4], are being adapted at single frequencies to determine the power delivered to the load (the horn, waveguide-to-coaxial adapter combination). This method in one form involves reflecting 100% of the power generated back down the line which would exceed the damage limits of the travelling-wave tube. A more complex form of the method may be used to avoid this,[5] but instead an isolator formed by a three port circulator with matched load is included to protect the travelling-wave tube.

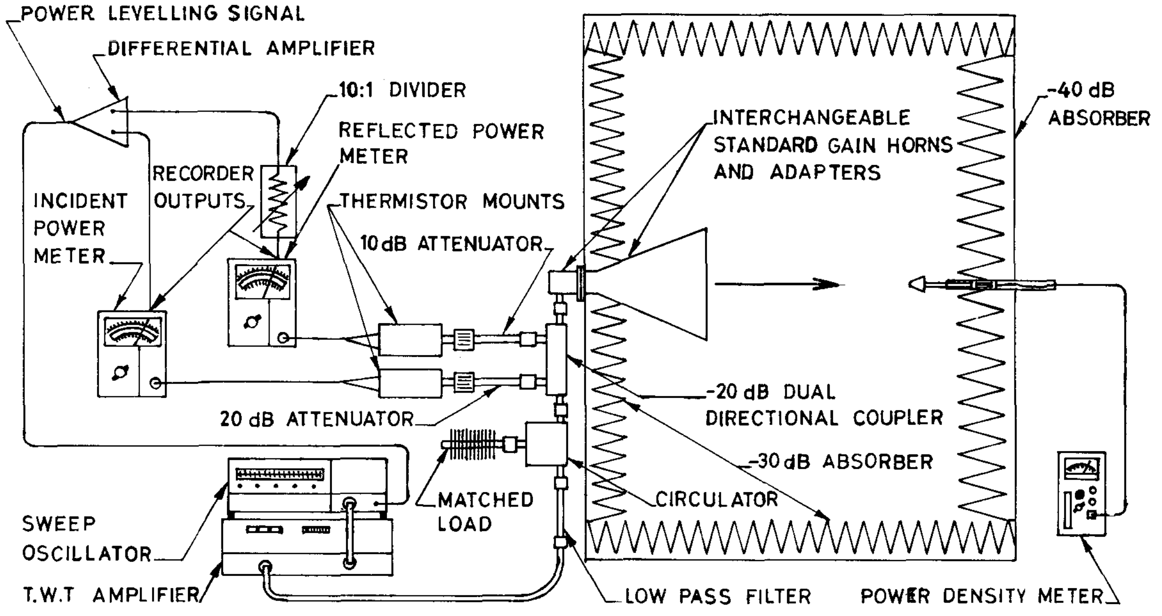

FIG. 3 SWEPT FREQUENCY CALIBRATION SYSTEM IN L AND S BANDS

The anechoic enclosure is presently being extended in a large room using almost 300 square feet of Eastern Microwave Corp. FFP-8 absorber. Purchase of more absorber is proposed to provide a target wall 12 feet by 12 feet square composed of 18" solid pyramidal absorber and a rectangular enclosure 16 feet long with sides, ceiling and floor made of 8" solid pyramidal absorber. As the frequency band is extended to range from 10 to 20,000 MHz it is proposed to enlarge and lengthen the chamber considerably to counteract the deterioration of absorber performance at the longer wavelengths. True far field measurements are planned in the future, requiring an antenna separation of at least ten metres. It is planned to develop the anechoic chamber as a very wide rectangular chamber with square wedged end walls. A "quiet zone" with - 30 dB reflectivity some ten metres long will be sought. It is proposed to adapt a Hewlett Packard Model 8755 Frequency Response Test Set recently purchased to examine the chamber performance as it is developed. The null-balance technique described by Buckley[6] will be used. Further, the near field gains measured in the chamber when low reflectivity is achieved will be checked by computing the near field (Fresnel zone) power transmission formula.

The calibration system under test and its further extension to wideband is expected to offer several advantages, including accurate swept frequency calibration over broad frequency ranges and over small bands around frequencies of special interest such as 2450 MHz. This is considered important to detect severe frequency response of monitors and allow for frequency variation of sources of microwave hazard.

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