A NEW INSTRUMENT FOR THE MEASUREMENT OF RESONANT FIELD DISTRIBUTIONS IN MICROWAVE HOUSINGS AND PACKAGES

Donald W. Griffin

Department of Electrical and Electronic Engineering,
The University of Adelaide, Adelaide, South Australia.

ABSTRACT

A special purpose two-dimensional standing wave detector for measuring resonant electric field distributions at the flat lid on microwave housings and packages is described and its use as a diagnostic and design development tool for module housings is demonstrated. Empirical and analytical relationships between measurables and the electric field are presented.

INTRODUCTION

Microwave housings and packages designed to provide precise physical support, good heat removal and excellent electromagnetic shielding for such components as monolithic microwave integrated circuits (MMICs), are usually broad-based, low profile rectangular, metal box-shaped structures. Most components, particularly semiconducting chips, are mounted on the broad floor of the housing while signal and bias connections are made via the narrow side walls. Assembly is usually completed by a flat metal lid fastened around the perimeter at the top edge of the side walls.

Such housings and packages will act as resonant electromagnetic cavities if it is not possible to include sufficient microwave absorbent material within the enclosure to prevent them being energised as such. Potentially resonant enclosures must be designed in such a way that the microwave performance of the assembly within the enclosure is not degraded in any way by either in-band or out-of-band resonances. Such resonances can cause undesirable electromagnetic coupling that may affect passive as well as active components in the assembly. The box shape favours TE followed at higher frequencies by TM mode resonances.

There appear to be few, if any, design aids specific to the problem of housing and package design. The wide range of geometric detail due to internal wall projections, component materials and dimensions, etc., adds complexity to any design analysis that aims to predict, (a) electromagnetic resonances, (b) details of associated electric and magnetic field distributions, (c) couplings between parts of the enclosed assembly due to resonances and (d) the resultant effect on performance characteristics.

NEW CONCEPT FOR MEASURING RESONATOR FIELD DISTRIBUTIONS

Features of the Method.

With the aim of testing housings and packages and developing design improvements a method of measuring the frequencies at which resonances occur and the distribution of the associated electric field intensity at the inside face of the housing lid has been developed and tested. The method does not require modification of the housing or package in any way nor does it need to use any of the connections to the microwave assembly within the housing. It is only necessary that the housing have a flat lid and that it be left off so that the housing can be mounted on an equivalent flat plate on the test instrument. The microwave assembly in the housing or package may be operated normally while resonant field distributions are being measured.

Choice of Coupling Structure for Testing Housings.

Almost without exception the coupling structures used with cavity resonators are either loops or irises placed in the end walls of cylindrical cavities of circular or rectangular cross-section. These coupling structures are fixed in position where the magnetic field tangential to the end wall is at a maximum and the electric field is zero. There is no fundamental reason why a straight wire probe extension of the inner conductor of a coaxial line should not be used as a means of coupling to electric field in the resonator. The coupling factor will depend upon the extension of the probe and the electric field at the probe position. Resonance can be excited by feeding microwave power into the cavity via the probe and adjusting the frequency until a minimum in reflection is obtained. By adjusting the extension of the probe and its position, critical coupling corresponding to zero reflection can be set.

Measurement of Electric Field Distribution.

If probe penetration is adjusted for critical coupling through the lid of a housing where the resonant electric field is a maximum then at other positions the cavity will be undercoupled and partial reflection of the incident microwave power will occur. The reflection will be a measure of the electric field at any chosen position relative to the maximum.

An assembly designed to exploit this effect and

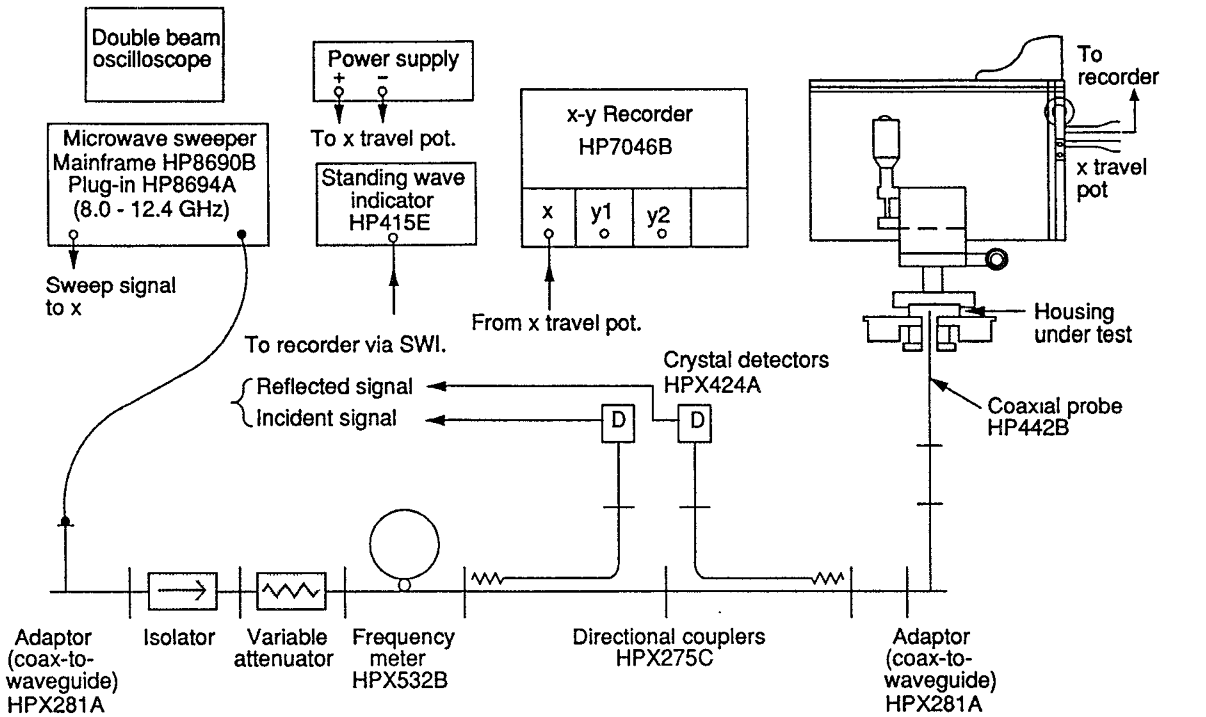

Figure 1. Schematic of the assembly used for measuring electric field distributions associated with resonances inside microwave module housings and packages.

yield plots of relative electric field normal to the inside surface of module housing lids is shown in Figure 1. The lid of the housing to be tested is replaced by a flat metal plate with a coaxial probe at its centre. Micrometer quality positioners are used to move the housing under test along a series of probe scan paths parallel to the longest side wall of the housing. A potentiometer, mechanically coupled to the scan path positioner, provides x-axis input to a plotter and the reflected microwave power, measured with a directional coupler and crystal detector, provides y-axis input. Some special preparation of the plate and the edges of the housing under test is necessary.

TESTING THE CONCEPT

To test the measurement concept a simple rectangular cavity made from a length of standard rectangular cross-section waveguide and resonant in modes designated as TE_{10n}, with n integral, can be used. The instrument shown schematically in the right hand part of Figure 1 does not have to be built for this test. Placing a short circuit on each end of a standard slotted line section as used for standing wave measurements creates a suitable resonator. The probe is used without a detector as shown in Figure 1 and the slot along the centre-line of the top wall of the resonator allows distributions to be measured. Sweeping the frequency over its entire range with the probe half way along the resonator will reveal resonances having n odd within that range. Repositioning the probe away from the half way point places it where modes with n even will have finite values of electric field normal to the top wall.

The frequencies at which absorption lines occur

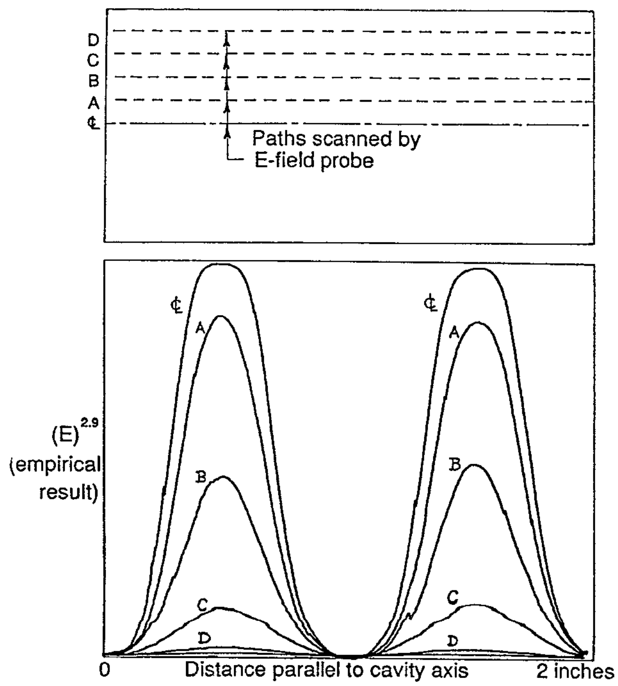

Figure 2. Measured TE_{102} resonant field distributions.

in the reflection characteristic agree with those calculated from the physical dimensions of this cavity. Selecting one and recording the microwave absorption as a function of probe position along the slot yields n maxima like those in Figure 2.

Simple Rectangular Cavity with no Top Wall

Constructing an instrument like that shown in Figure 1, and testing a simple rectangular cavity placed on the test platform of the instrument so that the probe can be moved along paths that extend throughout the lid area, yields the results shown in Figure 2 for the TE_{102} resonance. The five recordings reveal the essential features of the two-dimensional standing wave pattern and demonstrate that the instrument can be regarded as a special purpose two-dimensional microwave standing wave detector.

Derivation of an Empirical Calibration Law.

The electric field distribution for a TE_{102} resonance is known to be a sine function of the longitudinal and transverse coordinates of points on the surface of the lid. The measured results of Figure 2 are approximately equal to the theoretical distribution raised to the 2.9th power - hence the law shown on Figure 2.

EQUIVALENT CIRCUIT EXPLANATION OF THE METHOD

Probe and resonator equivalent circuits (1, 2).

The energised probe can be represented by a parallel combination of current generator I_P,

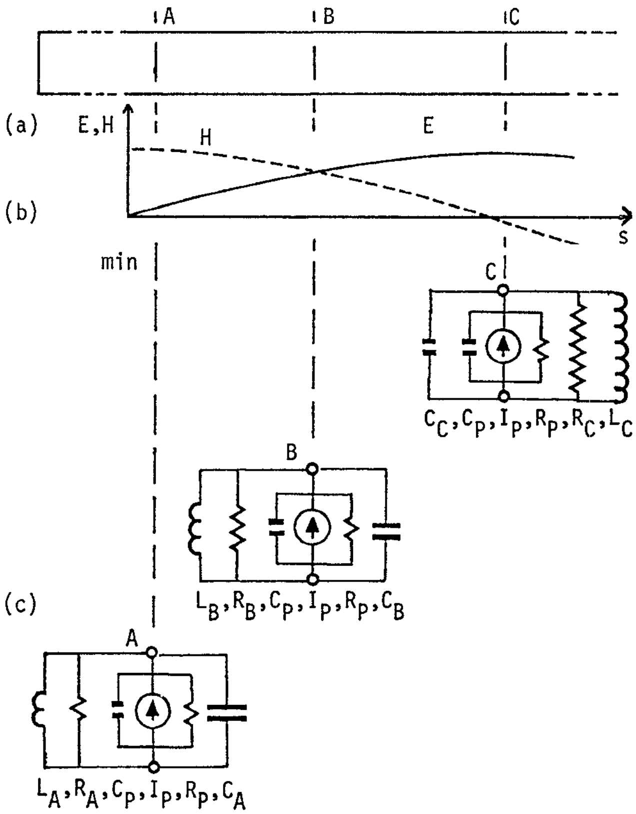

Figure 3. Equivalent circuits at probe positions in the electric field pattern in a rectangular cavity resonator, (a) resonator, (b) E-field from a minimum to an adjacent maximum, (c) circuits.

capacitance C_P and resistance R_P. I_P depends upon the microwave source that energises the probe as well as its geometry, whereas C_P and R_P depend upon probe geometry only, provided the probe does not come too close to the side walls of the housing and the floor of the housing is at a constant distance from the probe tip. Hence in Figure 3(c) the probe equivalent circuit is the same for positions A, B and C in the standing wave pattern shown in Figure 3(b).

The equivalent circuit for the resonator depends upon position. Near a minimum in the electric field distribution, at position A, the equivalent inductance, L_A, of the short circuited stub to the left is small and the equivalent capacitance, C_A, of that to the right is large. By contrast near an electric field maximum, at position C, L_C is large and C_C is small. At intermediate position B, L_B and C_B have intermediate values. The resonant frequency and the unloaded quality factor of the unloaded cavity should be invariant with position. This means that the equivalent loss resistance for the unloaded cavity varies with position such that $R_C > R_B > R_A$ and for critical coupling at the electric field maximum the probe penetration is adjusted to give $R_P \approx R_C$. Thus at position C incident power is entirely absorbed whereas at B and A undercoupling exists and only part of the incident power is absorbed.

The Law for Deriving Electric Field from Measurements.

The equivalent circuits allow several problems to be identified that make the derivation of a law complicated. As the probe is moved away from position C, not only is the probe coupling and the loaded quality factor reduced below the critical value, but the resonant frequency of the assembly is tuned away from the excitation frequency. As a result the absorbed power decreases more rapidly than would occur if excitation at actual resonance were to be maintained. Also, if the depth of the cavity below the probe is not uniform then C_P and possibly R_P may vary with probe position. Thus as a consequence of these complications measured results may be more useful from the qualitative rather than the quantitative viewpoint. If the aim is to diagnose and eliminate resonance problems in housings and packages then at least the method provides a means of testing practical structures where no comparable alternative exists.

UNWANTED RESONANCES IN A RADAR MODULE HOUSING FOR MMICs

Component Layout for Transmit-Receive (T/R) Operation.

A microwave ferrite circulator is needed in T/R modules so that the same antenna element may be used for both transmit and receive functions. A typical layout within a module housing is shown in Figure 4 where the circle represents the shield of the microwave circulator positioned in a corner so that it can be connected to (i) the power amplifier output, (ii) the antenna element external to the housing and (iii) the low noise receiver input, via minimum length striplines.

Measured resonances

The relative electric field distributions at resonant frequencies within the operating band of this are shown in Figure 5. Both families of recordings illustrate the dominant effect of the circulator shield on the in-band resonances. A gap between the top of the shield and the housing lid results in the formation of a re-entrant type cavity that resonates at 9.833 GHz as shown in Figure 5(b). That cavity is tightly coupled to the rest of the housing and tunes a resonance at 8.996 GHz as shown in Figure 5(a) that makes the open part of the housing one half wavelength long. The next resonance (not shown here) occurs at 11.775 GHz with the housing two half wavelengths long.

Interpretation of measurements.

At each of the resonances a relatively intense microwave magnetic field will be produced circumferential to the circulator shell. That field will pass in part between each of the three microstrip conductors, that emerge from the circulator, and the floor of the module housing. Thus there are three inductive loops coupled via common circumferential magnetic flux at each resonance that override the isolation of the circulator. Thus even though the measurements are not quantitative they provide invaluable qualitative information diagnosing major problems in module housing design.

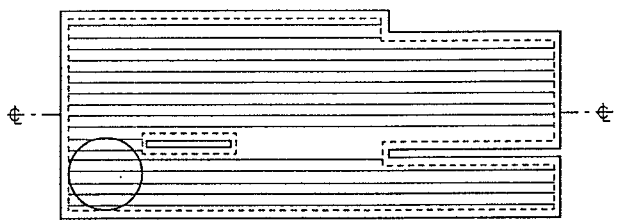

Figure 4. Probe scan paths within a phased array radar T/R module housing. (17 paths 0.050 inches apart, longest path 2.460 inches, plan also shows 0.420 inch diameter circulator housing, 2 septa and a side wall step.)

CONCLUSION

A novel method of finding electromagnetic cavity resonances and the electric field distributions inside housings has been demonstrated. It can be used to diagnose causes of malfunction of assemblies within the housing and the effectiveness of components designed to remedy faults.

ACKNOWLEDGEMENT

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REFERENCES

1. C.G.Montgomery (ed.), "Technique of Microwave Measurements", McGraw-Hill, New York, 1947.
2. Edward L. Ginzton, "Microwave Measurements", McGraw-Hill, New York, 1957.

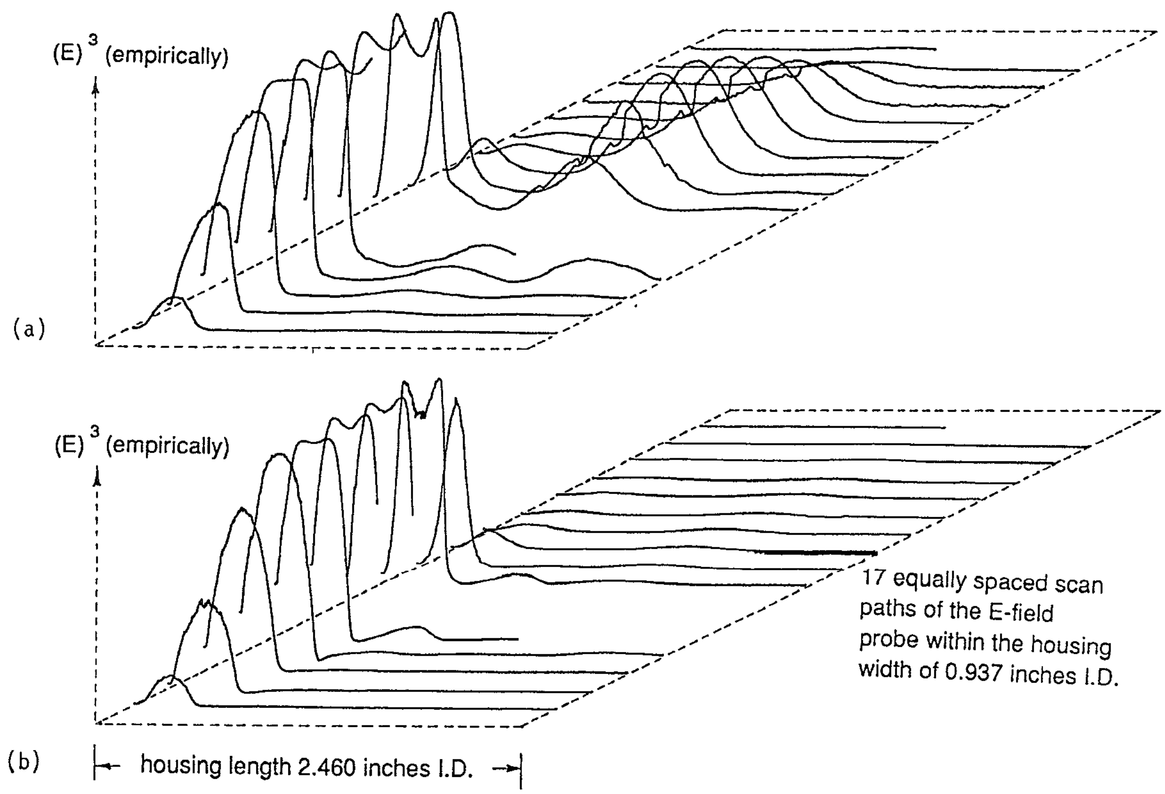

Figure 5. Measured E-field distributions for two resonances within the housing outlined in Figure 4. Resonant frequencies are (a) 8.996 GHz and (b) 9.833 GHz.