A Novel Method of Detecting Missing Parallel/Multiple Bond-wires in microwave transistors that is amenable to integration with automated test handlers

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Chin-Leong Lim
Avago Technologies Malaysia Sdn. Bhd.
11900 Bayan Lepas, Penang, MALAYSIA
Fax: 604-6437914, Email: chin-leong.lim@avagotech.com

Abstract — A method of detecting missing parallel or multiple bond-wires in packaged microwave transistors at the manufacturing test stage is described. Instead of the conventional way of testing the transistor in the amplifier configuration, the new method tests the device as an oscillator. Using the oscillation frequency as the screening criterion reduces test complexity and allows easy integration with existing automated test handlers.

INDEX TERMS — Bond-wires, emitter wires, source wires, ground inductance, microwave transistor, RF testing.

I. INTRODUCTION

In the packaging of RF / microwave transistors and Monolithic Microwave Integrated Circuits (MMIC), bond-wires serve as interconnects between the die and the lead-frame. The bond-wires are usually made from gold or aluminum with round cross-section and have diameters ranging from 0.5 to 1 mil. Though a bond-wire may be physically short in term of the operating wavelength, the parasitic inductance associated with it may be substantial depending on the manufacturing parameters such as length, diameter and height above ground [1]. The resultant parasitic inductance increasingly influences device characteristics as the operating frequency rises toward the microwave range.

In the common emitter/source amplifier, one of the most adverse effects of the inductance at the emitter/source terminal ($L_e$) is a reduction in the available power gain [2]. In a transistor amplifier with simultaneous input and output match, the inverse relation between the power gain ($A_p$) and $L_e$ in can be seen from [3]

$$A_p = 1 / (\omega^2 L_e C_{cb})$$

where $C_{cb}$ is the collector-base capacitance.

The combined inductance of the bond-wires and the lead-frame, forms an unintended series-series negative feedback [4]. To reduce the ground inductance of a packaged device, manufacturers commonly make connection to the source/emitter/ground contact of the transistor/MMIC die using two or more bond-wires in parallel. Ideally, the combined inductance ($L_{wp}$) of a pair of wires is half the inductance of a single wire ($L_w$). Due to the mutual inductance ($L_m$) of currents flowing in the same direction [5],

$$L_{wp} = (L_w + L_m)/2.$$  \hspace{1cm} (2)

The undesired additional inductance due to $L_m$ can be minimized by widening the internal angle between the twin bond-wires to reduce the mutual coupling [6]. However, the subsequent discussion will ignore the effect of $L_m$ for the sake of simplifying the explanation.
II. PROBLEM DESCRIPTION

Missing bond-wire due to assembly error is a frequent cause of customer returns. Unfortunately, units containing this error cannot be screened out by the most common production test parameters, e.g. gain and noise figure. To replicate applications with the highest customer base, 900 MHz and 1800 MHz are commonly chosen as the measurement frequencies in manufacturing test. If only one out of several emitter/source/ground bond-wires is missing, state-of-the-art microwave transistors with high gain-product bandwidth (fT) usually have enough margin to meet gain and noise figure specifications at test frequencies that represent the lower and consequently less demanding end of the device’s optimal operating range.

The X-ray machine is currently the only foolproof way to sieve out aberrant parts with a missing bond-wire. However, the X-ray screening is not an electrical test method and cannot be easily integrated with commercial high-speed test handlers. So, its use is presently limited to off-line failure analysis rather than in high volume testing. Electrical test methods involving the measurement of DC resistance, gain or s-parameters have been experimented with but are hampered by the lack of reproducibility in the high-speed test environment. A list of the electrical screening methods and their attendant problems are summarized in Table 1.

III. PROPOSED SCREENING SOLUTION

The majority of the microwave transistor will find application as amplifiers and this is usually reflected in the amplifier-centric choice of production test parameters. Parting from convention, this novel screening method tests the Device-Under-Test (DUT) as single port common base oscillator. Lb forms the part of the resonator that determines the oscillation frequency. Negative conductance, the condition for oscillation, is fortuitously created by the parasitic inductance (Lb) of the transistor’s base to lead-frame connection [10].

As the oscillation method is purely an RF measurement, it will be comparatively easier to integrate with existing automated test stations which most likely already incorporate RF-centric test instruments such as spectrum analyzers.

### Table I Summary of Various Electrical Screening Methods and Problems Arising From Their Implementation

<table>
<thead>
<tr>
<th>Screening method</th>
<th>Associated problems</th>
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<tbody>
<tr>
<td>4-wire ohmmeter (Kelvin contact)</td>
<td>The difference in resistance of a 2-wire unit and a 1-wire one is in the order of a mili-ohm or less. However, the variation in unit-to-unit contact resistance between the leads and the PCB trace is equal or even greater in magnitude [7].</td>
</tr>
<tr>
<td>Gain measurement (measured in regular production test-board)</td>
<td>At commercial test frequencies which are relatively low in comparison to the device’s fT, the gain reduction due to one missing wire is miniscule compared to the unit-to-unit and wafer-to-wafer gain variations.</td>
</tr>
<tr>
<td>S parameter measurement using vector network analyzer</td>
<td>Requires tedious &amp; error-prone calibrations at coax interface and also non-coaxial fixture compensation on the S parameter extraction fixtures (e.g. ICM &amp; Maury, etc.) [8,9]. Moreover, the fixture is too fragile for high-speed device insertion and its size too large to fit within the confined turret area.</td>
</tr>
</tbody>
</table>

Fig. 2 Comparison of a correctly manufactured bipolar transistor with two emitter-wires (left) with a manufacturing error containing one emitter wire (right).
The inductance of the lead-frame, \( L_l \), is the inductance of the wire-bond, and \( C_{\text{ext}} \) is an external capacitance used to resonate the circuit.

When the transistor has the full complement of two emitter wire-bonds in parallel, the effective inductance due to the wire-bond is half of the previous example. So, the oscillation frequency is given by:

\[
  f_{\text{osc}}' = \frac{1}{2\pi \sqrt{\frac{L_l + L_w}{2} C_{\text{ext}}}} \tag{4}
\]

It is apparent, \( f_{\text{osc}}' \) will be higher than \( f_{\text{osc}} \). So, the aberrant 1-wire DUT will have a lower oscillation frequency from its good 2-wire counterpart. The parasitics associated with the PCB traces, biasing resistors and other components will somewhat modify the oscillation frequency from what is predicted by these equations. However, the additional parasitics have been omitted from this highly simplified analysis as the intent is to illustrate the concept rather than arrive at an exact analysis.

**IV. RESULTS**

For validating the proposed screening method, bipolar junction transistors HBFP-0420 from Avago Technologies were used as the test vehicle. To represent manufacturing error, one of batch of the transistors was deliberately assembled in the industry standard SOT-343 package with one emitter bond-wire (1-wire DUTs) as opposed to the correct two bond-wires. Subsequently, the 1-wire DUTs were compared against known good transistors with dual bond-wires in the emitter connection (2-wire DUTs) using the described screening method. A spectrum analyzer was used for monitoring the DUTs’ fundamental oscillation frequency, though a frequency counter should conceivably be able to fulfill a similar role if either lower equipment cost or faster measurement time is required. The DUTs possessing the full complement of emitter bond-wires demonstrated higher oscillation frequencies than the parts with a single bond-wire.

Fig. 4 and Fig. 5 show the spectral output from 3 units of 1-wire DUTs and another 3 units of 2-wire DUTs, respectively. A pass/fail limit which was arbitrarily fixed at 2.0 GHz successfully sieved out the aberrant 1-wire DUTs from the good 2-wire ones.
Fig. 4 Spectral output from 1-wire (aberrant) DUTs showing oscillation frequencies below the pass/fail threshold.

Fig. 5 Spectral output from 2-wire (good) DUTs showing higher oscillation frequencies than the pass/fail threshold.

Table II summarizes the average oscillation frequency collected from measurement of 3 units each of 1-wire DUTs and 2-wire DUTs.

<table>
<thead>
<tr>
<th>No. of bond-wires</th>
<th>Average oscillation frequency (GHz)</th>
</tr>
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<tbody>
<tr>
<td>1 (bad)</td>
<td>1.928</td>
</tr>
<tr>
<td>2 (good)</td>
<td>2.077</td>
</tr>
</tbody>
</table>

REFERENCES