Production Assessment Methods for Anisotropic Conductive Film Bonding of Flat Panel Displays

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Abstract
Two methods of electrical characterisation have been assessed for their suitability for production assessment of anisotropic conductive film (ACF) joints on Printed Circuit Boards (PCBs). Both flexible and rigid substrates with a range of differently bonded test samples have been investigated. The two electrical techniques were non-linearity measurements, which characterise the third harmonic voltage generated in the joint when a pure sinusoidal current is applied to it, and high frequency electromagnetic time-domain reflectometery (TDR), which assesses the reflections from the joint when stimulated by a signal containing a wide range of frequencies.

The non-linearity measurements were shown to differentiate between well and poorly bonded samples with a greater degree of discrimination than DC resistance measurements. The high frequency electromagnetic TDR technique was not able to detect the effect of graduated bonding pressure on the performance of the bonds.

1. Introduction

Anisotropic conductive films (ACFs) have been widely used in electronics manufacturing for fine pitch interconnect for many years. Consisting of widely dispersed conductive spheres in an adhesive binder, they are bonded using temperature and pressure to trap the spheres between the raised surfaces of conductive tracks or bond pads on the substrates to be joined. This ensures electrical conduction in the z-axis, but the spheres are sufficiently isolated from each other to prevent conduction in the x and y axes (see Figure 1).

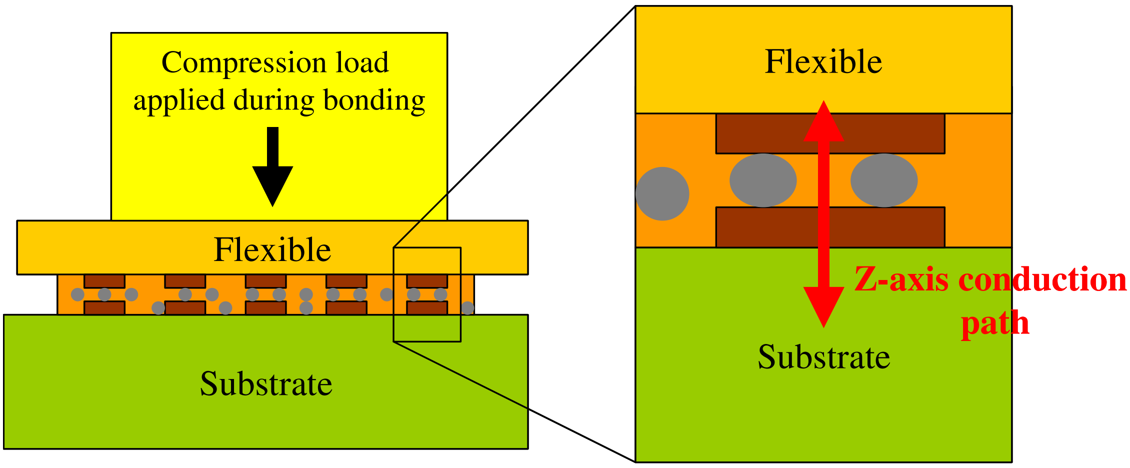

Figure 1: Example ACF bonding

The increased use of ACFs has been driven by their suitability for fine pitches. Their lighter weight compared to solders can also be used to advantage. Their low temperature fabrication has enabled them to be used in a wider range of applications than solder, particularly where the higher processing temperatures required by SnPb alternative solder alloys (required under RoHS legislation [1]), would be unsuitable. Available since the mid 1980's, anisotropic conductive adhesives have found applications in tape automated bonding (TAB) and flip-chip bonding, where they have the additional advantage of acting as an underfill, thus negating the requirement for further processing [2]. Industrial applications have included smart cards, disk drives and graphics drivers. ACFs have found a particular niche market in packaging flat panel displays. Here the materials are used to interconnect a flexible circuit to both the glass backed display and the display driver PCB. Flat panel displays are utilised in an extraordinary range of applications from calculators and mobile phones through to domestic white and brown goods, PC monitors and televisions. Ruggedised versions have also found applications in military and avionics electronics.

However, ACFs are still in their infancy when compared to the use of solders in electronics manufacture. Their conductivity can deteriorate over time particularly when subject to damp environments. Their impact strength has been shown to be poor and they have a lower current carrying capacity when compared to solders [3]. There are also critical issues in manufacturing such as controlling the bonding pressure and temperature to ensure that sufficient mechanical and electrical contact are produced. Poor temperature control can lead to adhesion failures, moisture ingression and resistance increases. Insufficient pressure can lead to conductivity problems as the conductive spheres will have poor contact with the upper or lower substrates surfaces. Excessive bonding pressure can lead to crushing of the conductive spheres. Where these are metal-coated polymer spheres, this may result in rupturing of the plating and thus poor connectivity. If the bonding head is not planar, then either or both of these conditions can exist in a bond.

Process control of the bonding process is limited. To ensure bond planarity, bonders can be characterised with pressure sensitive tapes to ensure even pressure across the bond. However, the industry does not have an in-process inspection tool to differentiate between acceptable and unacceptable bonds. Test methods are required as loss of performance, even in a single interconnect, is directly apparent to the end user as a non-functioning pixel on their flat panel display. Resistance testing can obviously be used to determine non-functioning joints, but no protocols are available to weed out joints which are likely to fail prematurely due to insufficient or excessive bonding pressures. The purpose of this work was to investigate the suitability of two electrical test methods, time-domain reflectometry and non-linearity measurements.

High frequency electromagnetic TDR is primarily used in the electrical and electronics industries to characterize and locate faults in cabling such as twisted wire pairs or coaxial cables. Applications in testing of high speed PCBs are also under development. Conventional TDR transmits a fast rise time pulse along the conductor. The method used here involved synthesising the fast rise time pulse using a Vector Network Analyser (VNA) to generate a series of measurement points over a broad range of frequencies. For a well terminated conductor of uniform impedance, a pulse will be absorbed at the far-end of the termination and no signal will be reflected. However, any discontinuities in the conductor will produce echoes that are reflected back. This is similar in principle to radar.

Linearity measurements of electronics components have been undertaken for over 30 years. The technique measures the third harmonic voltage generated in a conductor when a pure sinusoidal current is applied. If the conductor has a constriction, this causes an increase in the third harmonic voltage, and the technique has been applied successfully to screen component batches for unreliable components.

2. Experimental details

2.1 Test Vehicle

To determine if the techniques under assessment were capable of differentiating between well and poorly bonded samples, test vehicles with three different levels of bonding planarity were fabricated. To mimic the bond between a flexible and a display driver PCB, the test vehicle consisted of an FR4 PCB with ENIG (electroless nickel/immersion gold) finished tracks bonded to a polyimide flexible, again with tracks finished in ENIG. The tracks, when bonded successfully, form a continuous meander, alternately between the PCB substrate and the flexible substrate, across the width of the test vehicle. Test pads on the PCB allowed segments of the meander to be measured separately for comparison. For the TDR measurements, the end of the flexible substrate and the PCB were cropped as indicated in Figure 2, to provide a series of parallel tracks. The tracks were 125µm wide with a 125µm gap.

The test vehicles were fabricated using 45µm thick, thermoplastic based ACF with 2µm diameter Ni particles. Bonding was typically at 180°C for 10 seconds at 2MPa pressure. Samples were fabricated with three different bonding planarities; (A) normal, (B) mild misalignment and (C) gross misalignment. Figure 3 shows a bond height scan using laser profiling indicating a difference across the bond for a grossly misaligned sample of approximately 30µm (i.e. varying from approximately 210µm to 240µm).

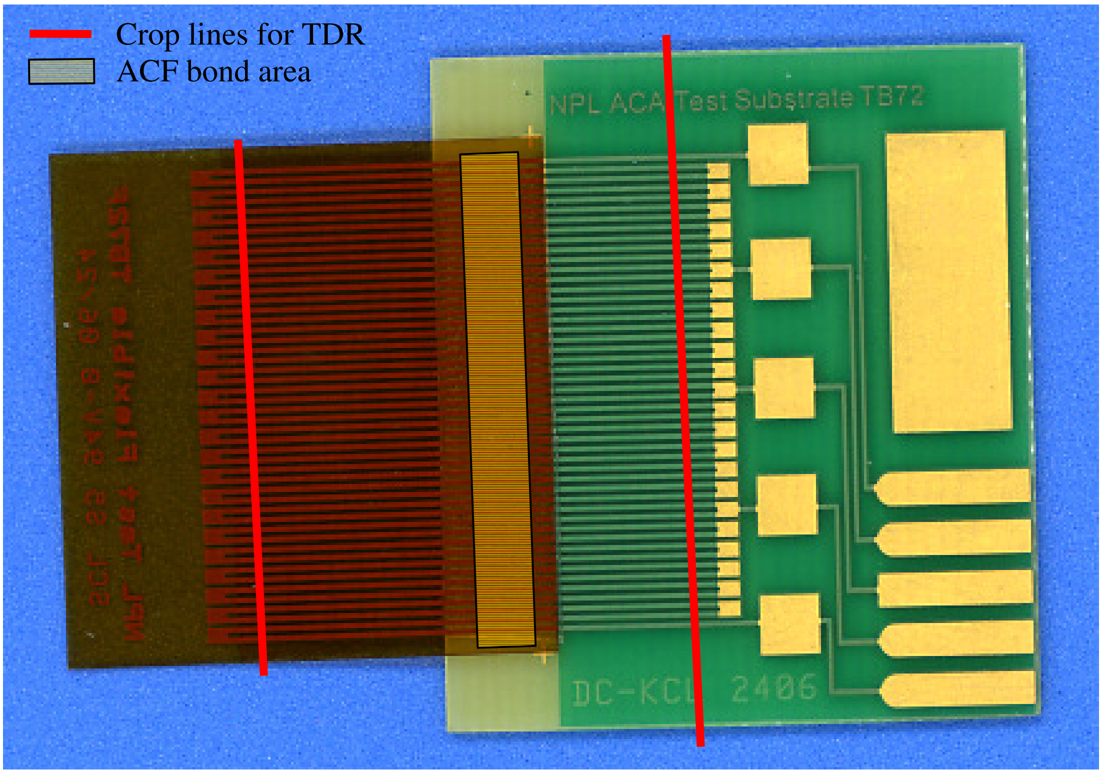

Figure 2: ACF test vehicle

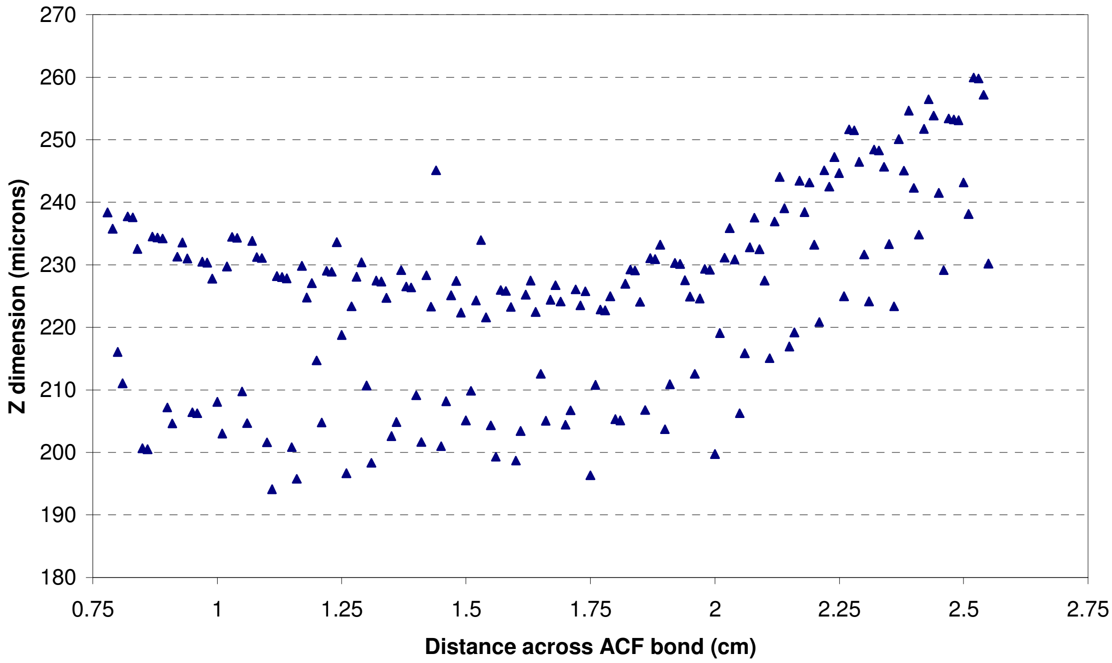

Figure 3: Laser surface scan of grossly misaligned test vehicle showing a variation in height of approximately 30 µm

2.2 Non-linearity testing

Non-linearity of a conductor is determined by selective measurement of the 3rd harmonic voltage generated when a pure sinusoidal current is applied to it. The harmonic voltage generated is given by the equation:

$$V = k\,l\left(\frac{I}{A}\right)^n \tag{1}$$

where k is the material constant, A is the area of the conductor, l is the length of conductor and I is the current. For resistive elements, n is close to 3. If the conductor has constriction or flaw (conduction only takes place over a fraction of conductive surface), the area A decreases locally, causing the 3rd harmonic voltage to increase following a cube law [4].

For this evaluation, an input frequency of 10 kHz was used with the voltage of the third harmonic frequency at 30 kHz being measured. The non-linearity of the conductor was calculated using the equation

$$\text{Non-linearity} = 20\ \text{Log}\ (V_{30kHz}/V_{10kHz}) \tag{2}$$

For linear components such as metallic resistors this value should be around -120dB.

2.3 Non-linearity testing results

A selection from the three batches of ACF bonded samples (A, B & C) were tested and the non-linearity values calculated are shown in Figure 4. Values for three sections of each meander across the ACF bond were calculated for each sample. Samples from batches A and B did not show any non-linearity, with values consistently calculated at around –120dB. However, for the C samples (those with gross misalignment) whilst two readings showed good linearity (~-120dB), the third value for each sample was significantly less linear (-70 to –50dB). Figure 5 shows all the non-linearity measurements for each of the three meanders on the grossly misaligned samples plotted against their respective DC resistance. The results fall into three distinct groups. The first group (lower left) indicates well bonded interconnects with both low non-linearity (~-120dB) and low DC resistance (<1Ω). The third group (top right) shows poorly bonded ACF joints with greater non-linearity (-70 to –50dB) and higher DC resistances (2.5 to 4.5Ω). In production it should be possible to segregate these two groups by electrical resistance measurements. The second group (top left) is of significant interest. These samples do not show a significant increase in DC resistance (<1.5Ω), but their non-linearity values were significantly higher at around -70 to –60dB. Thus after manufacture, this latter group would not be located by DC resistance measurements but could be separated using non-linearity measurements.

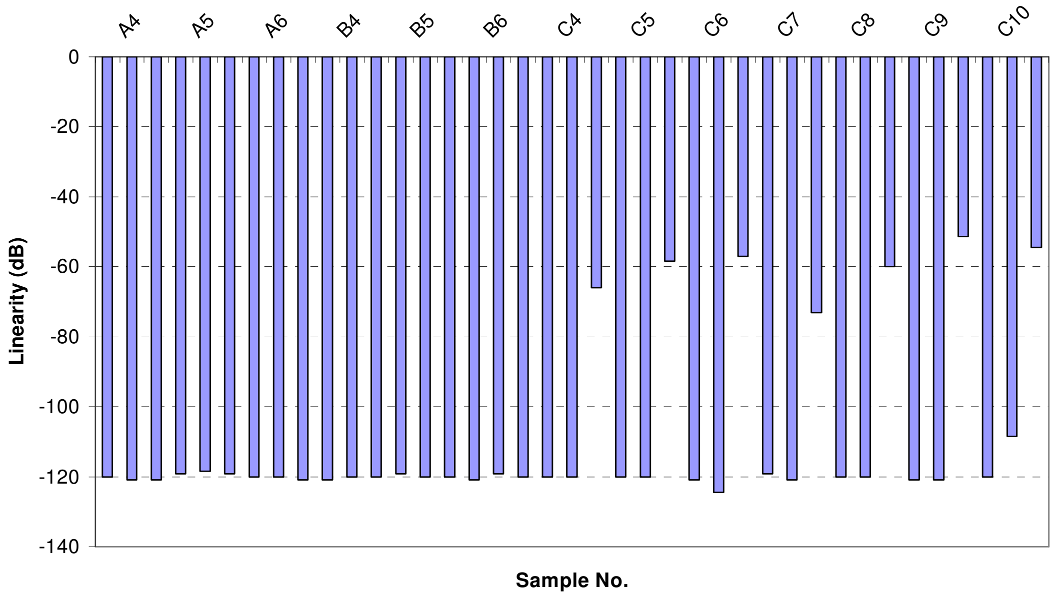

Figure 4: Calculated non-linearity values for three meander sections on a selection of ACF bonded interconnects

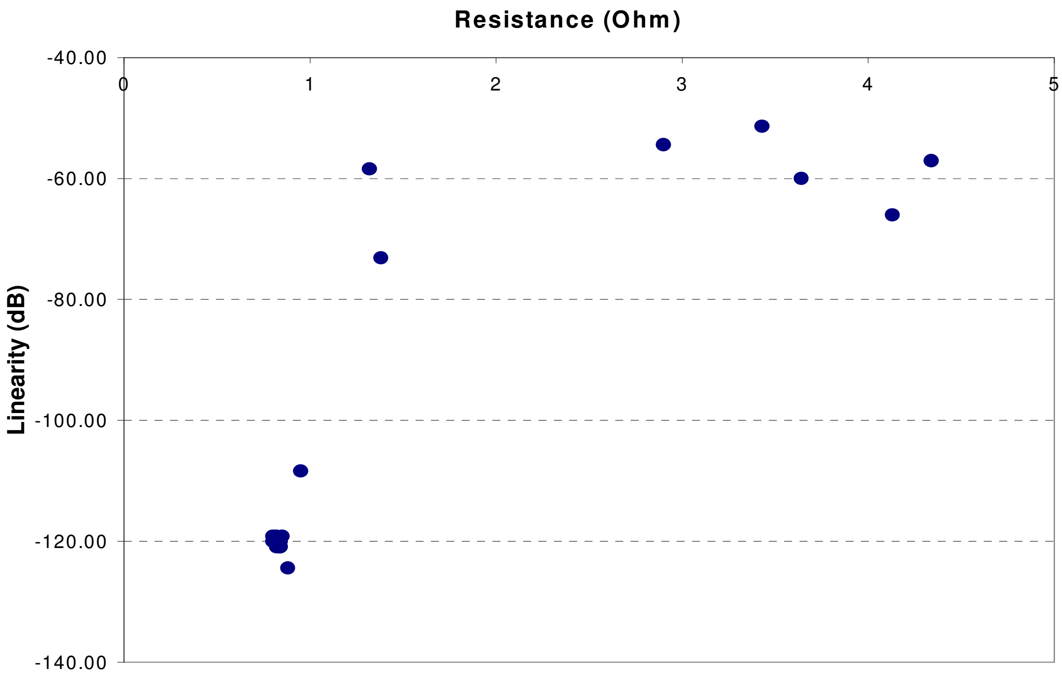

Figure 5: DC resistance of meander sections from C samples plotted against their non-linearity values

2.4 TDR

The test coupons for the time domain reflectometry measurements were similar to those used for non-linearity measurements but were without coverlay on the flexible portion and without solder resist on the PCB portion. The samples were cropped along the lines indicated in Figure 2 so that each sample consisted of a series of nominally straight, parallel, metallic conductive tracks mounted on top of an insulating substrate. For any given set of three adjacent tracks, these can be viewed as a form of co-planar waveguide (CPW) transmission line [5, 6]. The two outer tracks provide the ground for the transmission line whereas the central track provides the signal carrying line. Therefore, this form of transmission line is often referred to as CPW with a Ground-Signal-Ground (GSG) configuration. The high frequency electromagnetic properties of such lines can be measured using GSG on-wafer probes connected to a Vector Network Analyser (VNA) [7].

The test method used here relies on using a VNA configured to perform GSG CPW measurements using on-wafer probes. The VNA measures the reflection response, in terms of the magnitude of the complex-valued Voltage Reflection Coefficient (VRC), of each CPW line and displays the result in the time-domain (i.e. as a function of time). If the wave velocity, v, is known, then the magnitude (or amplitude) of the VRC, can be displayed as a function of distance, d, using:

$$d = \frac{v \times t}{2} \tag{1}$$

where t is the displayed time and the factor 2 takes account of the there-and-back travel of the wave due to reflection. For the investigations reported here, the VNA was operated in time band-pass mode. A more detailed description of this method has been given in [8].

2.5 TDR results

A selection from the three batches of ACF bonded samples (A, B & C, as detailed above) were measured. The results are shown in Figures 6 to 8. The peak at zero is due to the launch, the peak at 65ps was shown to be due to the end of the PCB, and the peak at approximately 120ps has been shown to be the end of the flexible substrate, and the small shoulder or peak at 40ps is due to the start of the bonding area [8]. Hence the results show the key features of the sample, and in principle therefore, applicability of the TDR technique is proven. However from the above linearity measurements the samples are known to have variable joint characteristics, and that variability is not seen in Figures 6 to 8. The most likely modification of the results would be seen in the peak at approximately 40ps. This peak does not show significant differences between the three conditions of varying bonding pressure and so the test method does not seem to be able to detect any change in performance of the bond due to varying the bonding pressure.

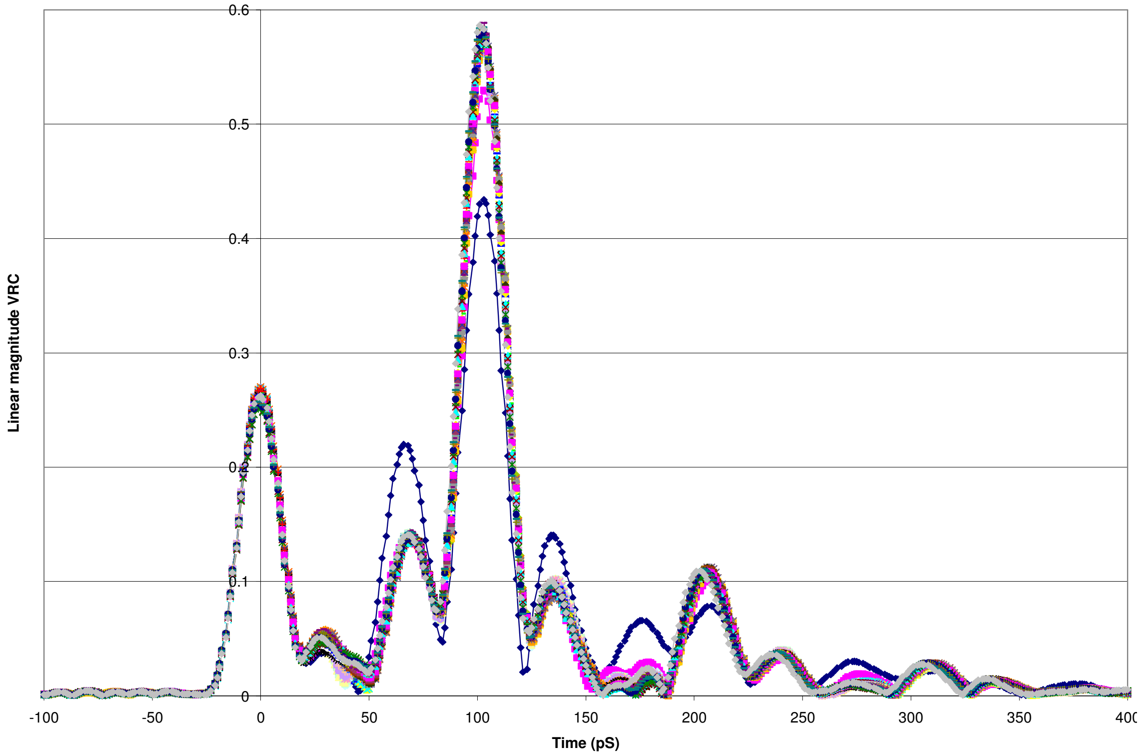

Figure 6: Sample A1, bonded using normal bonding pressure

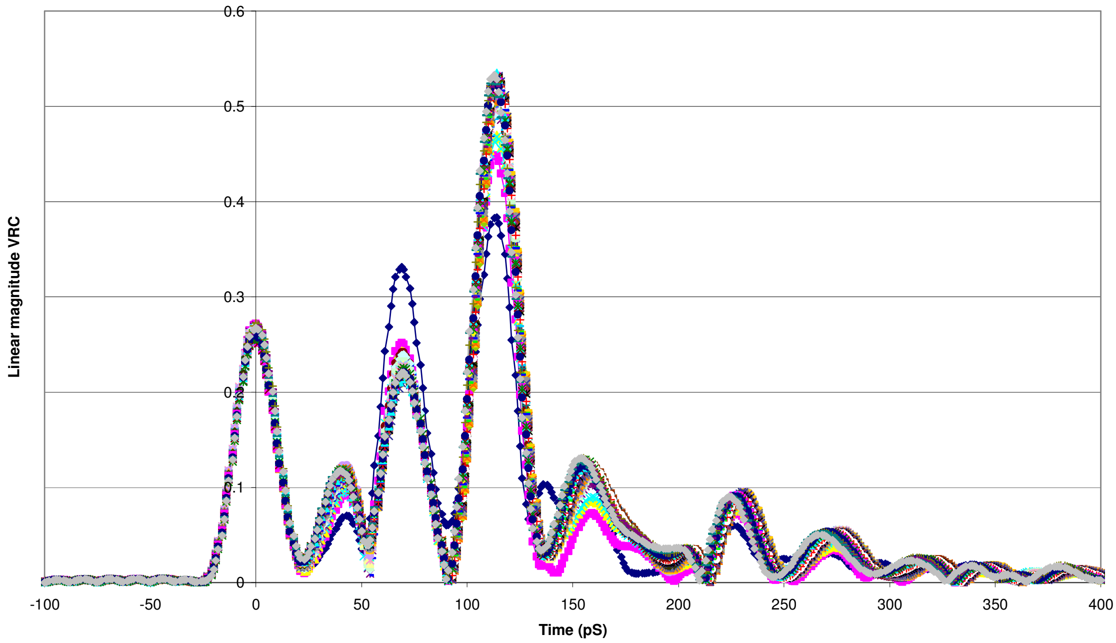

Figure 7: Sample B1, bonded using a mild misalignment of bonding pressure

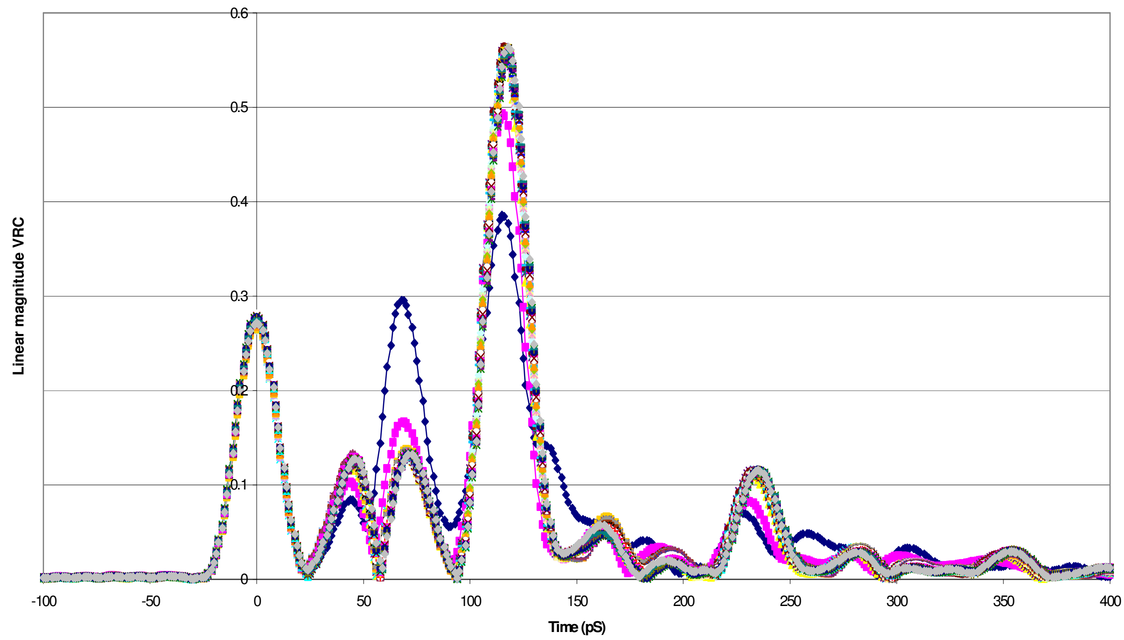

Figure 8: Sample C1, bonded using gross misalignment of bonding pressure

3. Summary

From the above investigation, the following conclusions can be drawn concerning the use of non-linearity measurements and the high frequency electromagnetic TDR technique:

1. Non-linearity measurements were able to distinguish between well bonded and poorly bonded samples with significantly better differentiation then DC resistance measurements
2. The high frequency electromagnetic TDR technique was not able to detect the effect of graduated bonding pressure on the performance of the bonds.

For the non-linearity measurements, future investigations will concentrate on ageing the samples measured above to determine whether, during ageing, the non-linearity of all bonds increases or if this is limited to the more poorly bonded samples.

Potential future investigations that could be undertaken to improve the sensitivity of the VNA-based TDR system and test method so that changes due to ageing and/or bond pressure may become discernible, include:

1. Perform tests using different signal bandwidths;
2. Use a more sophisticated form of time-domain analysis (e.g. low-pass step and/or impulse modes [9]);
3. Use time-domain signal processing (e.g. gating functions to help isolate features of interest [9]).

4. Acknowledgements

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5. References

[1] DIRECTIVE 2002/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment; http://www.rohs.gov.uk/Docs/Links/RoHS%20directive.pdf

[2] Kivilahti J.K. and Savolainen P.: Design and modelling of solder-filled ACAs for flip-chip and flexible circuit applications; Conductive adhesives for electronics packaging, edited by Johan Lui, Electrochemical publications 1999, ISBN 0 901150 37 1

[3] Fan, S. H. and Chan, Y. C.; Current-carrying capacity of anisotropic-conductive film joints for the flip chip on flex applications; Journal of Electronic Materials, Feb 2003

[4] Salamon A. and Trianello T.; Component linearity test improves reliability screening measurement of third harmonic index; 11th Annual Reliability Physics Symposium, 1973, pp69-76

[5] Gupta, K. C. et al; Microstrip lines and slotlines, 2nd Ed, Artech House, Norwood MA, 1996.

[6] Simons, R. N.; Coplanar waveguide circuits, components and systems, Wiley Interscience, New York, 2001

[7] Lucyszyn, S.; RFIC and MMIC measurement techniques, in “Microwave Measurements” chapter 11, in “Microwave Measurements”, 3rd edition, Institution of Engineering and Technology, Electrical Measurement Series 12, edited by R J Collier and A D Skinner, pp 217-262, 2007.)

[8] Wickham M., Salter, M., Ridler, N., Dusek, M. and Hunt, C.; On-wafer testing of PCB tracks as CPW lines as a production assessment method for anisotropic conductive film bonding: NPL Report MAT 18, National Physical Laboratory, April 2008.

[9] Agilent Time Domain Analysis Using a Network Analyzer, Application Note 1287-12, 2007. (Available from www.agilent.com.)