Keysight Technologies
Maximizing DDR BGA Probe Bandwidth for Superior Signal Fidelity

Application Note
The use of BGA probes for probing DDR DRAM is becoming more popular and almost a requirement as memory design gets more complex and compact and data rate gets higher. DDR3 and DDR4 data rate is increasing from 800MT/s to possibly 3200MT/s. Memory system designers now have huge concerns on current DDR BGA probing design meeting the high bandwidth requirement for best signal fidelity. Signal fidelity is important for making accurate DDR measurement for compliance as per JEDEC specification. Memory designers also need to make signal integrity measurement for margin testing. Margin gained from removing DDR BGA probing effect can be used in less tolerant components in the design. This paper describes a new probe correction method used to extend the bandwidth of the DDR BGA probe to provide more margins in signal integrity testing and minimize error introduced by the DDR BGA probe.
The memory system design is trending towards smaller packages, stressing more capacity and less power consumption. Designs are getting more spacially tight and the data transfer speeds are increasing from DDR3 to DDR4. This calls for smaller embedded board designs with very little board space to place footprint or connector to probe key DDR signals (clock, strobe and data) for validation and testing. Probing has become a very challenging task for designers. Probing at the wrong location will cause reflection and distort measurement result. Placing the wrong probe on the system can load the system and affects the signal fidelity and will cause errors in slew rate, rise time, setup and hold time measurements. To help overcome this probing challenge, engineers now adopt the use of DDR BGA probing. DDR BGA probe is designed to have small keep out volume (KOV), is almost as big as the DRAM size and provides signal accessibility from the memory device, DRAM to the oscilloscope for making signal integrity measurement (Figure 1). The use model requires the BGA probe to be soldered onto the system and the DRAM to be soldered onto the BGA probe. This needs to done with a BGA rework station. The scope pads at the sides of the BGA probe provide connection to the oscilloscope with solder-in probe heads.

The DDR BGA probe is able to support close to 2GHz of nominal bandwidth. The bandwidth of the BGA probe would need to be close to 8GHz to be able to support DDR3 and DDR4 data rate above 1600MT/s. With a little compensation using probe correction methods, the BGA probe can correct for loss of amplitude and bandwidth due to the probe’s lossy characteristic. The loss caused by the BGA probe is more prominent as you probe at higher data rate, above 1600MT/s. Previous probe correction method allows users to apply a transfer function in the oscilloscope with waveform transformation software to compensate for the BGA probe. The transfer function file is built with S parameter files of the BGA probe and the solder-in probe head. The S parameter file of the BGA probe can be obtained through direct measurement with a vector network analyzer (VNA), time domain reflectometer (TDR) or simulation software. While effective, this method requires significant knowledge of the measurement equipment or the simulation tool and the transformation software.

Figure 1. DDR3 BGA probe acts as an interposer between the DRAM and the system board to provide DDR signal accessibility from the DRAM to the oscilloscope with solder-in probe heads.
The latest probe correction method with the oscilloscope enables an oscilloscope user to perform a very accurate tip-to-scope AC calibration of the DDR BGA probe without any additional instrumentation such as the VNA or TDR. The oscilloscope performs this AC calibration by outputting a fast edge. The Keysight Technologies, Inc. 90000X-S series scope can output 15ps edge to completely characterize VSource, VIn, and VOut (which includes probe loading characteristics), and combining this measured information into a custom correction filter for DDR BGA probing setup. The method allows user to perform probe correction on each signal on the BGA probe and eliminate probe characteristics which are dependent on manufacturing variations.

**DDR BGA probe correction procedure**

To determine the correction that will be applied to an individual probe the probe needs to be characterized. The procedures to perform DDR BGA probe correction involve setting up a thru fixture and then perform an AC calibration with the oscilloscope. The following describes the steps to set up the BGA probe with a thru fixture (Figure 2):

1. Apply solder balls to all of the ground (VSS) signals on the outer rows of the BGA probe.
2. Apply solder ball to a signal on the BGA probe that requires probe correction.
3. Level or planarize the solder balls by rubbing the BGA probe gently on a large piece of ceramic.
4. Cut out two pieces of z-axis connection material (elastomer contact) and tape them on each side of the thru fixture to provide contact between the solder balls and the thru fixture.
5. With the help of a microscope, align the BGA probe on top of the thru fixture so that only the signal of interest contacts the transmission line and all of the ground balls contact ground on the thru fixture through the elastomer contacts.
6. Connect the thru fixture to the channel input of the oscilloscope and feed CAL out from the oscilloscope to the thru fixture with a SMA cable.
7. Solder the probe head to the oscilloscope pads on the BGA probe and connect to one of the channel inputs.
   - VIn is defined as the signal at the BGA probe point while the signal is being loaded by the BGA probe.
   - VOut is the signal that is output from the BGA probe.
   - Vout/Vin Correction, the signal at the output of the probe is an accurate representation of the signal that currently exists, as it is being probed.
The AC calibration can be performed on the Keysight oscilloscope with PrecisionProbe software. PrecisionProbe software characterizes and compensates custom probes with the Infiniium series oscilloscopes. PrecisionProbe characterizes the BGA probe’s frequency response (either VOut/VIn or VOut/VSrc) and then creates a custom filter that is loaded in oscilloscope hardware to perfectly flatten the frequency response of the BGA probe. Loss on the DDR BGA probe is then compensated for and higher bandwidth on the oscilloscope can then be achieved. In addition to measuring the frequency response (both magnitude and phase), PrecisionProbe also provides impedance plots generated in the AC calibration process and there is also a bandwidth control to allow user to remove unwanted high frequency noise with a filter. This probe correction method ultimately allows user to simulate an ideal probe without spending enormous amount of engineering time and money to design one.

Figure 3. PrecisionProbe frequency response magnitude plot shows a flat frequency response after applying a custom filter to compensate for the DDR BGA probe loss. An ideal DDR BGA probe has a flat frequency response up to its bandwidth (-3dB point, or the point at which the signal level is attenuated by the probe to 71% of the original signal), and that minimally loads the circuit to which it is connected. The before and after effects on the waveform after PrecisionProbe calibration is shown in Figure 5. Data, DQ rise time is improved by 30% with corrected bandwidth from 2GHz to 5GHz. Real time eye diagram measurement reveals that eye height and eye width measured is improved by 5mV and 14ps.
Figure 4. PrecisionProbe frequency response deviation from linear phase shows that the BGA probe response can be corrected to support bandwidth close to 10GHz.

Figure 5. Rise time on DQ measures 191.06 ps after PrecisionProbe calibration versus 274.5ps before probe correction on W2635A DDR3 BGA probe at 1333MT/s.
Figure 6. Real time eye diagrams on before and after PrecisionProbe calibration on read data probed with W2635A DDR3 BGA probe at 1333MT/s.

DDR technology is now widely used in the mobile application industry due to its lower cost and support for low power consumption. Because of the mobile industry design and technology driving towards smaller form factor size and increase data rate of memory, the memory validation task is now extremely difficult if not impossible without a device that gives access to the DDR signals directly at the balls of the DRAM. The DDR BGA probe helps memory designers gain access to the DDR signals to make signal integrity measurement with the oscilloscope for compliance as per the JEDEC standard. While most probing is designed to meet the bandwidth requirement of the signal probed, there are tradeoffs that need to be made on other factors such as size and cost of design and manufacturing. With the help of probe correction tool such as Keysight’s PrecisionProbe, memory designers can easily migrate to new DDR technology with the use of existing DDR BGA probe design. Making measurements on high speed memory (DDR3 and DDR4 memory technology above 1600MT/s) with DDR BGA probe requires the use of PrecisionProbe software to help extend the bandwidth and provide more margins for signal integrity testing. There are also other system parameters such as source and receiver impedances, line lengths, loss, and characteristic impedances which can have great effect on performance and need to be taken into consideration when creating a transfer function model. Evaluating the waveforms using these devices particularly for higher bit rate systems will require the combined implementation of de-embedding software such as Keysight PrecisionProbe and InfiniiSim (Waveform Transformation Toolset).
Keysight Technologies Oscilloscopes

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