

“01005 Assembly, the AOI route to optimizing yield”

Abstract

The increasing demand for smaller & smaller portable electrical devices is leading to the increasing usage of extremely small components in the SMT assembly lines.

With the introduction of 01005 packages in mass production, all the different stages of the line are facing new challenges: from board design, through component placement to reflow process. Each stage introduces some specific types of defect which are considered impossible to repair due to the small size of the package. AOI has become an essential tool to enable good yield in the assembly of 01005.

Different AOI criteria have to be considered in order to implement the optimum strategy that will achieve top quality products with high throughput of the line.

The Miniaturisation Era

Over the past ten years, we have seen tremendous changes in our lives with the introduction of a range of various portable devices for consumers such as mobile phones, PDAs, MP3 players and GPS', as well as the integration of more electronics in medical devices like pacemakers or hearing aids. These devices integrate more and more functions in smaller packages to satisfy our increasing demands for performance or comfort.

In this environment, The Electronics industry had to adapt to develop new PCBs (Printed Circuit Boards) which could be integrated into these products. The race to build smaller and smaller PCBs is long running, demanding the smallest component. The smallest of these: 01005 component packages are now enabling further dramatic savings of space and weight on the PCBs.

At first, 01005 components were predicted to be restricted principally to medical applications where the key driver is size, not cost. Now, on reaching their production stage, their cost has dramatically reduced and now they are widely integrated into many consumer devices. Compared to their closest relative, the 0201 component packages, which are 2.25 times bigger, they are only around 25 times more expensive, which makes them more interesting now as their price drop down fourfold since their introduction.

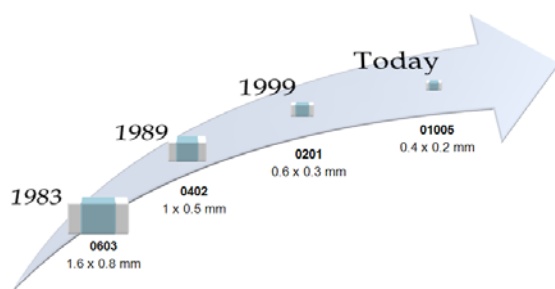


Fig1. Evolution of passive packages size over the years

Almost invisible to the naked eye (0.2 mm x 0.4 mm) and extremely lightweight (0.004 mg), 01005 represent a real challenge for assembly. Qualified production sites are capable of producing PCBs with 01005 passive components, but they all face increased difficulties. The assembly process becomes a headache due to their extremely small size where rework is near impossible.

01005 assembly process challenges

Since their introduction in the early 2000s, 01005 packages have been the focus of many studies requested by PCB manufacturers to find appropriate process settings, through PCB design, solder paste process, P&P (Pick&Place) and reflow.

Many equally important parameters throughout the SMT line have to be controlled even more tightly to guarantee a stable and viable process where 01005 packages are assembled.

PCB design

The board design is the first parameter to be optimized with the objective of reducing the populated area on the PCB without sacrificing the yield. Special attention has to be paid to the pad type, dimension and gap as well as the minimum space between 2 components.

Knowing that the pad type will have a big impact on the printing, placement and reflow processes of 01005 assembling, it has to be chosen carefully. Today, 3 different pad types are used:

- NSMD pad (Non Solder Mask Defined): widely used in SMT, the solder mask opening is larger than the metal pad size. Solder is allowed to wrap around the sides of metal pads.
- SMD pad (Solder Mask Defined): used for small packages where copper extends underneath the solder mask.
- Semi-SMD pad: a combination of the 2 above enabling the stencil to sit on top of the solder mask and stabilize the 2 parts.

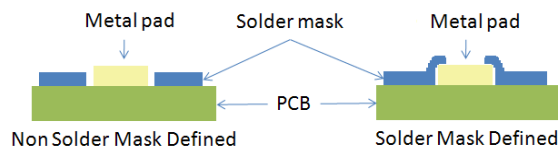


Fig2. NSMD and SMD representation

Optimization of the pad dimensions together with the minimum spacing between components is also critical to avoid solder bridging after reflow.

The separation (or the space between the 2 pads) is known to be a key factor in the creation of tombstone defects after reflow and are recommended to be less than 0.150 mm.

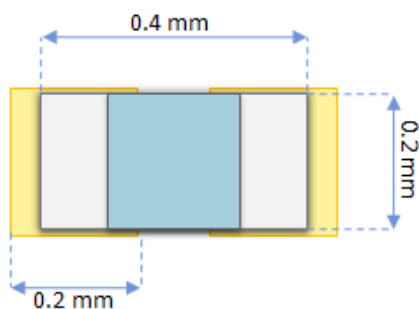


Fig3. 01005 and pad dimensions

PCB fabrication

During PCB fabrication, the plating of the pad has to be consistent to avoid defect creation after reflow. Misregistration of the solder mask over the pad is also a root cause for solder bridging as it will cause excessive solder on the component joint.

Solder paste process

It is proven that the printing process causes 49% of the overall defects, including the majority of solder bridging and insufficient or excessive solder issues. Different key factors interact during the printing process and require a specific attention to avoid defect creation.

The first challenge lies in the definition of the stencil, the optimized thickness of which will enable correct placement of small and large packages on the same PCB. Many studies came to the conclusion that 75µm is the optimum thickness for placing 01005 and applying the exact amount of solder for reliable connections. To guarantee the consistency of the print process it is also recommended to use an electroformed stencil that presents the sharpest aperture edges thus producing better transfer efficiency of the solder paste to the pad.

The solder paste itself has a big role in defect formation after reflow. Solder paste, such as type 4 or 5 (with average solder sphere of 0.031 mm and 0.018 mm respectively), with good printing property and fine enough powder size is recommended; following the rule that 5 balls of powder should fit in the smallest stencil opening. The use of small solder powder also emphasizes the self-alignment "floating" effect that is known to happen during the reflow process and reduces misalignment defects.

Screen printing parameters (speed, pressure and separation speed) as well as cleaning frequency are eventually critical during 01005 assembly. They can lead to a higher risk of blocking apertures, causing insufficient solder, and also paste & flux contamination residues on the stencil, causing solder bridges or excess solder.

The importance of controlling the printing process using an automated optical system can already be emphasized at this stage. 100% Solder Paste Inspection (SPI) provides the information, leading to solutions to stabilize the printing process and ensure a correct solder paste application on the PCB. The SPI, providing alarms upon defect opportunities, is an essential process control with these components. *(Refer to below part of this article for more details)*

Component placement process

After the definition of the critical settings for the material that will receive these miniature packages, the selection of the placement system has to be considered carefully. Accuracy and repeatability are the 2 key factors to successfully place 01005 on pads which represent only twice the electrode length of the package!

To eliminate the 6% of defects linked to the placement process, it is essential to control package placement conditions. An efficient pick-up can be obtained only if package quality & size are under control, tapes are of high quality and feeder units have correct fiducials. Adjustment of component position will reduce the risk for bill-boarding and face-down defects. In order to obtain the required accuracy, the placement machines are equipped with vision systems to verify the component position on the nozzle. The limit of this verification is that it only occurs while the component is held by the nozzle and not when it is at its final location: on the solder paste. This is why pre-reflow AOI (Automated Optical Inspection) is so important. Not only the AOI will control the placement of the component over the pad and solder paste, but it will also analyze the trends and prevent the formation of defects. Providing real time SPC analysis, AOI is able to generate proactive alarms and put the process under control. *(Refer to below part of this article for more details)*

Some Pick & Place machines can also ensure that no component is lost after pick-up and before placement so it can reduce missing defects. Because of the very small size and light weight of 01005 package (only 0.004 mg), the force applied on the component needs to be controlled carefully to avoid component cracking.



Fig4. Termination exploded due to excessive force applied during placement

Maintaining the flatness of the PCB during the placement of 01005 to reduce vibration will then avoid component shifting. Even if the self-centering effect will probably happen during the reflow process, it is observed that placing 01005 with an offset bigger than 0.050 mm will generate skewed component defects after reflow.



Fig5. Skewed component due to inaccurate placement

Reflow process

The reflow process is the last contributor to defect generation during 01005 assembly; it can cause around 43% of the total defects observed at the end of line. The challenge of this process is establishing and maintaining the best heating profile which can accommodate small and big packages at the same time. A Nitrogen environment is recommended for the reflow of small packages in order to achieve acceptable solder joint quality. Nitrogen has the advantage to reduce oxidation especially prevalent for lead free solder paste. For ovens with air, the reflow profile has to be carefully adapted to suit the 01005 which can render handling of big packages more difficult.

The majority of defects which happen during the reflow process are tombstone and floating components. A tombstone defect corresponds to a perfectly standing component whereas a floating component is properly soldered on one side and not attached on the other side. These defects can be easily identified by a post-reflow AOI which provides a precise analysis of the solder joint.

As already mentioned, the self-centering effect during reflow has a beneficial impact on 01005 packages even where lead free solder is used. Unfortunately, it has limitations and will not eliminate all misalignment errors.

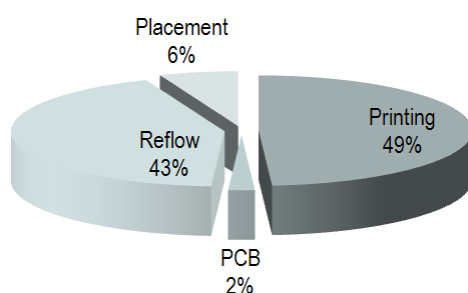


Fig6. Repartition of the 01005 defects root causes

Rework

Due to their extremely small size, it is absolutely impossible to consider doing some adjustments of 01005 at the pre-reflow stage of the assembly line.

Post-reflow rework is also quite impossible and very expensive to achieve. The soldering tips are too big compared to the size of the package to unsolder and it is difficult to get a safe mechanical contact to transfer the heat. This manipulation is necessary done under a microscope and becomes risky for the other components and/or the pad.

This is why for implementation of 01005, a more controlled process is required and only where AOI is in place this can be achieved to optimize process parameters as well as check the final quality of the product.

AOI Strategy in 01005 Process

Today, it is not necessary to prove the benefits of AOI in SMT lines. The Return-on-Investment (ROI) of these systems is now established and fully adopted by a majority of PCBs makers.

Bringing real added value to the final product, AOI becomes totally essential in 01005 assembly process as human inspection is extremely difficult and rework is not possible.

For standard SMT lines, AOI usage is optimized by placing the machine at the earliest possible stage of the process. The sooner a defect is detected, then the lower the repair costs.

The AOI placement options available for standard lines need to be adapted for 01005 as repair is not possible, which means that preventing and not finding the failures early is required. Post printing SPI and pre-reflow AOI are placed early to enable quick, precise process control, controlling the process and not only inspecting it. However as 01005 are more sensitive to reflow settings, post-reflow is still ideal to really get the best possible line performance, in terms of quality and cost.

As highlighted on above, bridging, floating and tombstone are the most common 01005 defect types. Also, the pie chart (Fig6) shows 01005 process defects are typically caused before reflow, printing process representing 49% compared to 43% for reflow.

Clearly this demonstrates the benefit of locating AOI (SPI) post print to identify print defects as early in the process as possible. At this stage, the PCB would not be touched up but can be cleaned and pasted again, and the printing parameters can be adjusted in real time.

Two different methodologies of paste inspection machines are available utilizing either 2D or 3D inspection capability.

2D provides good information on the pad surface coverage and position of the solder paste.

3D inspection will add height, volume and shape measurement capability, providing more precise data for the 01005 process, and will gain in acceptance as the inspection tool of choice.

3D SPI is used for process monitoring purposes in volume production, controlling for example stencil cleaning frequency, and in the NPI (New Product Introduction) stage it can dramatically contribute to optimizing the stencil printing parameters.

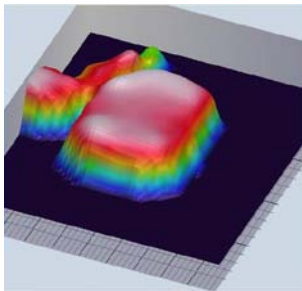


Fig7. 3D view of a 01005 solder pad with a bridge defect

Pre-reflow AOI is important and here again, rework is not possible. Some studies have demonstrated that 01005 components using small solder powder exhibit a self-alignment effect during reflow process. Some chips or resistors that were inspected with a deviation of less than 0.050 mm were properly placed and soldered at the end of the assembly line. Even if this phenomenon is observed, it cannot be considered as a constant of the process conditions. For a process to be in control, the placement machines must accurately place the 01005 on their pads.

Thus, pre-reflow AOI plays a fundamental role in this accurate positioning as it can feedback relevant data of X Y and angular deviation to the placement machine.

In fact, integration of a powerful real time SPC engine in the SPI & AOI is a key driver to implement such a process control strategy. This SPC engine has to record accurate placement deviations and analyze trends to indicate potential defects formation.

Ideally AOI will automatically generate and report alarms to the placement machine enabling real time interaction to modify the placement settings. This closed loop between the AOI and the placement machine provides major benefits in the placement of such small parts, as the accuracy window to place the component is so small.

Post-reflow AOI is also essential to ensure final product quality in 01005 lines and to ensure that defects created during the reflow process, typically solder joint related, are adequately identified.

Post-reflow AOI ensures that these defects will not escape as visual inspection is impossible. Some defects like floating or pillow can be identified by the AOI, which may be missed at the ICT (In Circuit Test) because the electrical continuity can still be there.

For above reasons, the optimum AOI strategy for 01005 lines would be multiple AOI, namely post-print, pre-reflow as a process monitoring tool and post-reflow AOI to ensure final product quality.

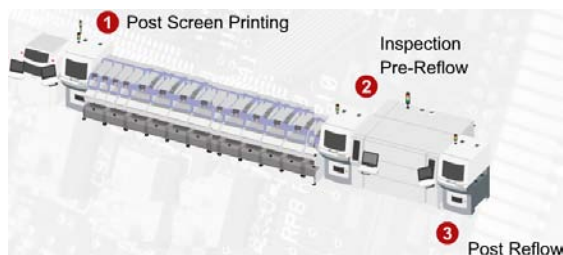


Fig8. Multiple AOI strategy in 01005 process

01005 repair is extremely difficult if not impossible, so the only way to save production cost is to prevent defects occurring by thoroughly analyzing the production process throughout the line to improve the process itself.

Combining SPC data from upstream SPI / AOI with post-reflow AOI, can be very useful to identify relationships between final defect and earlier process, and to improve the process itself. Therefore, with multiple AOI, each with powerful SPC tool, it is possible to trace defects back through the process for each single component. This enables to understand where in the process the defect was caused and where to initiate corrective action.

For example, when post reflow AOI detects a shifted component, with SPC data from multiple AOI, it is possible to trace back that this mislocation defect was due to a shift in the solder printing, or shift in the placement machine, or even to some combination of these process factors, based on factual data.

By determining the problematic process right away, corrective action can be taken to bring the process back under control.

When the defect-causing process pattern has been established, then the real time SPC with defect prevention alarm can be applied more effectively for self-perpetuating improvements. This is similar to processes without 01005 components; however, the fact is, when rework is not possible and production settings are so tight, this strategy becomes even more essential.

01005 challenges for AOI

Implementing 01005, has not only impact on the different equipments in the SMT line, but also on the AOI as it has to adapt to these miniature packages and provide good capability to precisely locate the component and detect defects.

For an inspection machine to be 01005 capable, there are several key factors to look at.

Magnification/Speed

To be 01005 capable, usually, demands greater resolution from the AOI. The general need of PCB makers to reduce cost of their products means that line speed is increasing and the AOI needs to be faster in operation, so it would not represent a bottleneck in the line. These two demands are in conflict and generally create a dilemma for the AOI designers.

Many companies are using state of the art image detectors with a native pixel size typically around 7 microns. The size of a viewed pixel at PCB level is determined by the magnification of the objective lens used. For a given detector the smaller is pixel size at the PCB and the smaller is the FOV (Field of View), the longer is the inspection time.

In other words, magnification is usually a trade-off of machine throughput. If pixel size is reduced to allow more accurate inspection of 01005 (0.2 mm x 0.4 mm), it usually decreases machine's throughput due to smaller FOV. If an AOI tries to acquire sufficient pixels for 01005 by decreasing pixel size, this often overkills inspection for large parts, and affects production throughput.

Several alternative approaches are offered to solve this dilemma with varying degrees of success.

Some manufacturers try to make pixels scalable. This approach involves that chosen pixel size must remain constant throughout the inspection process and will require physical manipulation to modify the pixel size which will impact overall throughput.

Some manufacturers went even further to make scalable pixel size within one inspection process. This will not much affect the inspection time at first sight. However, the fact is that this does increase inspection time to some extent, especially where the small components are disperse over the PCB area. This approach usually relies on mechanical switching systems which are one other variable and may well degrade system repeatability.

Some manufacturers suggest using multiple cameras with different magnifications. They can be programmed to change resolution within one inspection process. Again, this minimizes the impact on the inspection time by using better resolution only when it is necessary. However, again the inspection time delay depends on how much the smaller components are disperse on the PCB.

Another option is to use multi-mega pixel cameras. This approach makes resolution selective, but maintains the same FOV. This means, while in high resolution mode, it uses more pixel numbers to obtain same FOV while in low resolution mode, it uses less pixel numbers for same FOV. However, processing time of high resolution mode can be longer. Again there may also be an issue with cross compatibility of cameras.

Vi TECHNOLOGY, on the other hand, uses a more sophisticated different solution: Vectoral Imaging with sub-pixel capability. The key point here is that this approach does not depend completely on the pixel size as others do. Sub-pixel techniques yield the inspection of object features with a higher resolution than the native pixel grid. This works for component positioning and also for solder joint inspection. The powerful algorithms calculate the exact value of each pixel contributing in the inspection area and return exact value to enable accurate and precise joint analysis. With this approach, AOI does not require different pixel scales for 01005 components thus there is no trade-off between magnification and machine throughput.

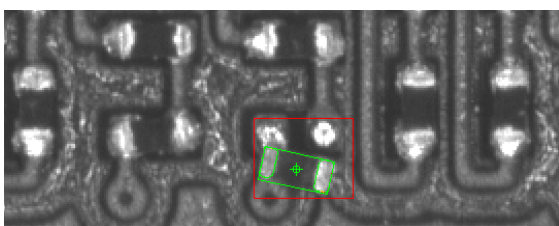


Fig9. Shifted capacitor accurately located with Vectoral Imaging

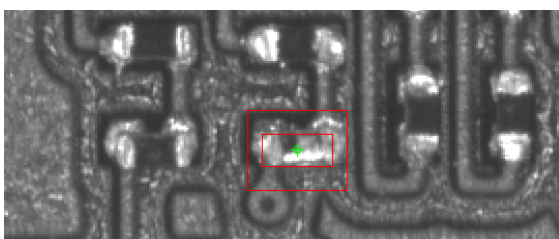


Fig10. Billboard capacitor accurately located with Vectoral Imaging

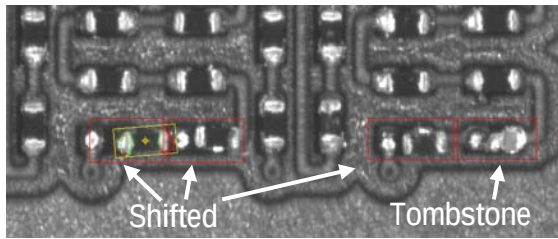


Fig11. Series of defects: 3 shifted components and 1 tombstone detected with post-reflow AOI

Accuracy

The accuracy of AOI obviously becomes more critical when inspecting 01005 components.

To minimize false calls, then the AOI must be able to measure position extremely accurately, which in turn allows the use of small, precise search windows. Further, to examine solder joints, then the AOI has to be intelligent enough to relocate the solder joint search window following the measurement location of the component. Together with the powerful and flexible algorithms to locate the components, Vi TECHNOLOGY uses highly accurate linear position encoders to ensure this level of accuracy in the camera positioning.

There are several components that can contribute to a high accuracy AOI which can be reliable for 01005 inspection.

Axis

Linear motors with high resolution optical encoders are bringing the required accuracy enabling the system to place the centre of camera FOV on a precise position and then measure component position deviation. Axes themselves must be mounted within a stable framework to ensure consistent performance.

Lens quality

Even when FOV centre is placed on the precise position, if the optic system includes too much error in the image compared to the real object, accurate inspection is not going to be possible.

As most of AOI use bigger FOV for 01005 inspection to maximize inspection speed, more and more AOI started to implement low distortion lens trying to solve image problems inside FOV.

One must be aware that the quality of commercially available telecentric lenses is not high enough for 01005 inspections. In fact, telecentricity is an essential property in metrology to determine the precise size of objects independently from their position inside the FOV and even when their distance is affected by some degree of unknown variations, such as PCB warpage or dilatation.

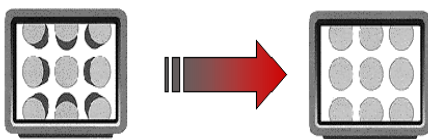


Fig9. Telecentric lens eliminates perspective distortion

Vi TECHNOLOGY uses a customized state-of-the-art telecentric lens with minimum distortion, some 10 to 20 times better than commercially available telecentric lens.

Let's take an example of a 60 x 45 mm FOV. With 2% of distortion, which is observed by good photographic optics, the error in positioning can be up to 0.74 mm, which is absolutely not acceptable for 01005 when its size is only 0.2 mm. With optics that has distortion smaller than 0.05%, its maximum position error is 0.014 mm, which is a lot better than commercial lens.

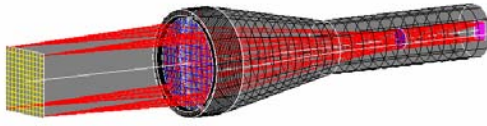


Fig10. Customized telecentric lens with high quality

Image Processing Algorithms

Having a true image (without distortion thanks to telecentric lens) in entire FOV is still not enough for accurate inspection to precisely locate the component position and then the inspection windows. The image analysis relies on powerful image processing algorithms.

Vi TECHNOLOGY's Vectoral Imaging tool extracts and locates features (object contours), converts them from the pixel grid to vectors, and analyzes them as geometrical shapes. A previously stored set of vectors (either extracted from an image or generated from CAD data) is compared to the vectors extracted from the run time image.

This tool has an accuracy of up to 1/40th pixel in position and 1/50th of a degree in rotation on defined targets.

Conclusion

The use of 01005 components in production is steadily increasing.

All steps in the assembly of these small packages have to be optimized: from board design, through component placement to the reflow process.

AOI is also challenged by the use of 01005 but the technology is ready and available to achieve accurate component location and reliable defect detection.

As visual inspection and rework are not possible, AOI is no longer an option in these SMT lines it becomes absolutely essential.

The ideal scenario is to implement AOI at each of the fundamental steps of the SMT line: post-print & pre-reflow as a process control tool and post-reflow as a quality keeper.

To be reliable in the 01005 process, an AOI must be of the highest capability and equipped with powerful solutions to overcome resolution accuracy and inspection throughput, as well as having the capability to return reliable data to control and improve 01005 process.

With the advent of the 01005, it is no longer satisfactory to find defects with only image correlation. This does not stand as a solution to overcome line demands in terms of both speed and accuracy.

A combination of state of the art algorithms with high performance optics and reliable hardware is the only AOI solution to give the expected performances for the 01005 process.

Vi TECHNOLOGY has taken up the challenge and provides state of the art AOI, equipped with the latest innovations, to enable consistent low defect assembly of 01005 on cost and quality optimised products.

References: Process optimization of an 01005 by Peter Grundy and Mats Magnell.(2006)

Written by Cathy Combet, SMT Product Manager at Vi TECHNOLOGY, April 2010

About Vi TECHNOLOGY

Vi TECHNOLOGY is a worldwide global supplier for the design, manufacture, and support of a wide range of innovative, Automated Optical Inspection (AOI) equipment and software solutions for a multitude of [applications](#); including [PCB assembly](#), back-end [semiconductor production](#), incoming inspection and process control.

Our goal is to create value for customers by developing [technologies](#) which follow the evolution of our shared market. Our R&D program focuses on enhancing existing products as well as offering technological breakthroughs to achieve a sustainable level of excellence. With nearly 20 years' experience, our systems meet even the most demanding requirements in terms of accuracy, repeatability, speed, and quality. We are confirmed leaders in the AOI market and offer [turnkey solutions](#) to maximize Return-On-Investment, decreasing cost-of-ownership in manufacturing plants. Our equipment is supported by world-class [service](#) with a [24-hour hotline](#) ensuring fast response times. We also have a strong network of 200 fully trained agents and distributors in [America](#), [Asia-Pacific](#) and [Europe-Africa](#), to ensure any issues are reported immediately to our offices.

Our many customers include the Number 1 player in the automotive electronics market, the Number 1 in the contract electronics manufacturer, and the Number 1 player in the mobile phone industry.

Our mission is to serve our customers worldwide to reach our Total Customer Satisfaction goals.

Further information on Vi TECHNOLOGY is available at www.vitechnology.com.

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