IV MAXIMUM PARAMETER SPEED SETTING

17% Speedup was achieved just by running at machine maximum speed settings. The optimum maximum speed parameter for search level, search speed, dwell time, plunge up speed and PRS die detect pre-time were determined by our Process Control team members without compromising the product quality.

The speedup was less applicable to a minority of devices that required an excessive amount of bonding dwell time. This is because the bonding dwell time constituted the major part of the cycle time.

IV.I EFFECT OF MAXIMUM PARAMETER SPEED SETTING

As expected, running an ageing machine at maximum speed settings is not sustainable. A series of containment actions were taken to counter the undesirable side effects. The side effects are, servomotor overheating resulting in premature failure; increased stoppages due to failure to detect a small die. Greater machine-to-machine variation in speed is detected. Increased wear on die-pickup device ('collet') and greater machine-to-machine variation in accuracy.

IV.II CONTAINMENTS ACTIONS

The necessary contaminant actions were taken to counter the maximum parameter speed side effects. All actions were subjected to sustained monitoring and proven to be sufficient.

IV.II.I AGGRESSIVE COOLING OF SERVOMOTORS

Running with maximum parameter resulted in a servomotor temperature of 52ºC, exceeding the manufacturer's maximum allowable temperature at only 50ºC. Compressed dry air is blown on the servomotor. This action alone is insufficient; the hot air had to be vented by cutting ventilation holes in the machine hood and back cover. In addition, an extra high-capacity fan was added to the back cover. With both modifications the maximum servomotor temperature is safe at 43ºC.

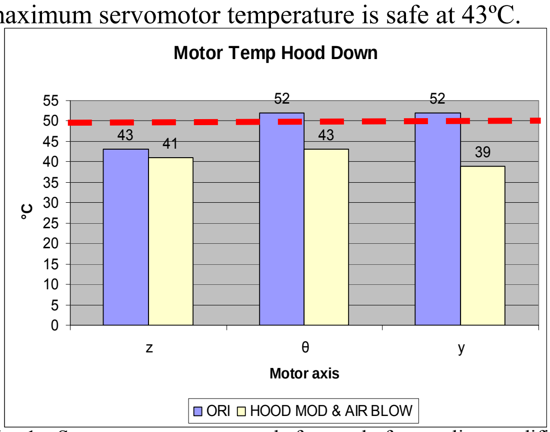


Fig. 1. Servomotor temperature before and after cooling modifications. Maximum servomotor allowable specification temperature 50ºC. (Chart by Yuserizal)

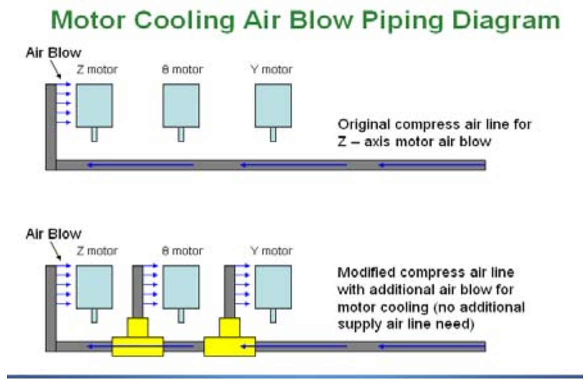


Fig. 2 Air blows cooling diagram. (Diagram by Yuserizal)

IV.II.II BETTER OPTICAL DIE-PRESENT SENSOR

Original Keyence FS2-60 analog amplifiers pick-up miss detect sensor response time is marginal for smallest die (260um x 260um) for high speed bonding. Change to Keyence FS-V31 digital amplifiers with faster response time with wide setting adjustment window.

New sensor configuration is FU-49X Sensor Head pair with FS-V31 digital amplifiers. Results from the changes are stable die detect absence present operation. Ease of adjustment and no assistance needed from highly skill person. Robust setting for variety dies range and recordable setting value.

Table 1 Sensor amplifiers specification comparisons

Specification	**FS-V31**	**FS2-60**
Response time	33µs (high speed mode)	260µs
Timer mode selection	Selectable on-delay/ off-delay with user specified value (0.1ms - 9999ms)	Selectable on-delay 40ms / off-delay 40ms
Sensitivity adjustment	Push button with digital reading (0-9999)	Analog 8-turn trimmer (est. 1-64)
Threshold Window (depend on die)	100 – 1500 (amp. reading)	22 – 25 (trimmer steps)

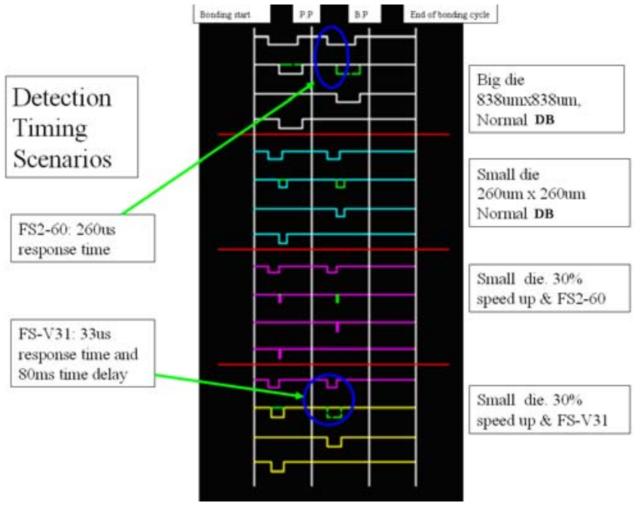


Fig. 3 Pick-up miss sensor detection timing scenarios comparisons; P.P – Pick-up position, B.P – Bonding position. (Diagram by Yuserizal)

IV.II.III Main Controller Board, Initial Program Loader and Software Upgrades

Machine to machine speed variation are reduced by standardizing all machine parameters. Before doing so we standardized the version of software in use. This required an increase in static RAM capacity as well as a change to high-speed EPROMs.

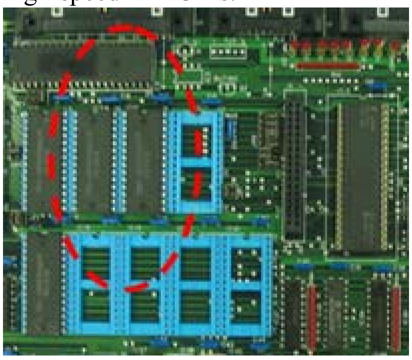


Fig. 4 One of two host controller boards; Static RAMs circled in red (Photo by Emelia Khamis)

IV.II.IV Pick-up Tools Enhancement

Collet wear is dependent on over travel, pick-up setting, bond force, diameter and material used. A new collet was successfully identified after a study. Also a new touch down sensor was identified for better touch down sensitivity.

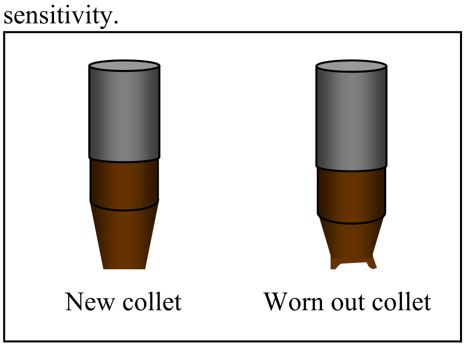


Fig. 5 Collet wear, exaggerated for clarity (Diagram by Harmit Singh)

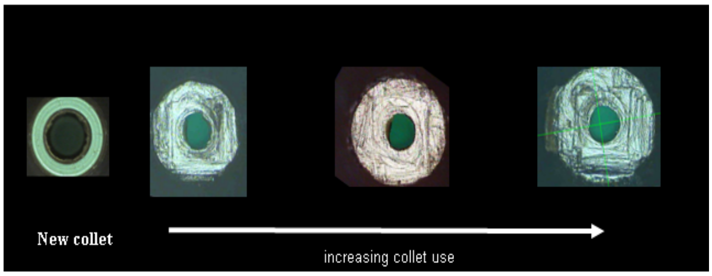
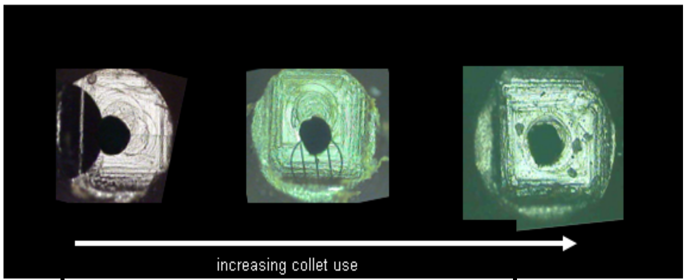


Fig. 6 Progressive collet wear. Note collet X shape is due to high power scope focusing indicator. (Photo by Harmit Singh)



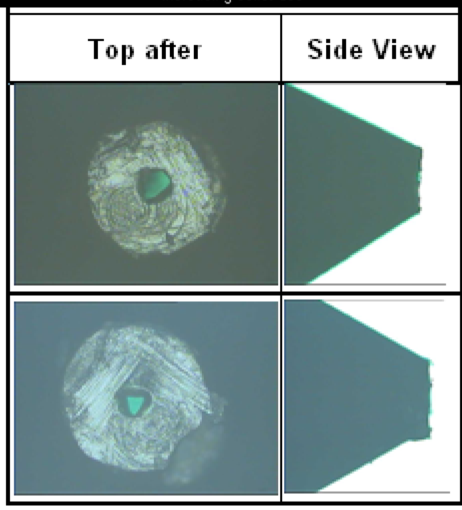


Fig. 7 Effect of different bond force setting, top , low, bottom, high. (Photo by Yuet Chuan Tan)

V Electronics Speed-up

Over-clocking is the fastest and cheapest way to increase speed for electronic processors. This method to increase the computer processor speed is well known. The processor system clock setting is simply set to a higher value. The down side with this method is that it overheats the processor. It can also result in premature failure due to metal electro-migration. To minimize this, we selectively over-clocked the minimum number from the eight available CPU boards and then subjected them to extended temperature monitoring. It was found that only the Hitachi SH-1 CPUs need to be over-clocked, and the temperature rise was negligible. Also, not all axes need to be over-clocked to the same degree.

V.I Servomotor Controller Processor

30% Speed up for die bonder is achieved without capital investment by over clocking the machine servomotor controller processor. The maximum speed up that can be gained this way is 40% with heat & stability still in acceptable range. However, the machine structure vibrations are extremely high. At 20% - 30% speed up the machine structure vibrations are much more acceptable, especially with modification on mechanical components and additional cooling system for the servo motors.

V.II Servomotor Controller Driver Board

At the heart of the system is a Hitachi SH-1 Series SH7034 "Super-H" HD6477034F20 16-bit RISC microcontroller. The SH-1 is the precursor to a full-blown DSP, and has DSP features. It has a 20MHz System Clock, the fastest in the SH-1 series, 64KB OTP Internal ROM, 2KB Internal RAM, 4KB External RAM all mounted in a PQFP (Plastic Quad Flat-Pack) resulting in very short PCB interconnects. Short interconnects are good news for over-clocking. The SH-1 has relatively low power operation, making it more suitable for over-clocking.

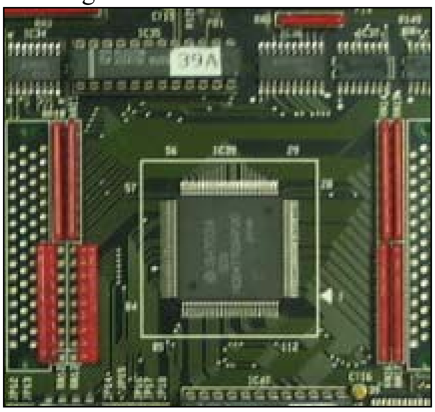


Fig. 8 Picture of Wafer Holder X-Axis Servomotor Controller (Photo by Emelia Khamis).

V.III Over Clocking

Three attempts of experiment are studies for system over Clocking. All the results were convincing.

V.III.I Over Clocking First Attempt

System clock is supplied by an 8-pin program-selectable DIP Kinseki EXO-3 20MHz. We managed to find only 1 higher frequency direct replacement, at 24MHz.

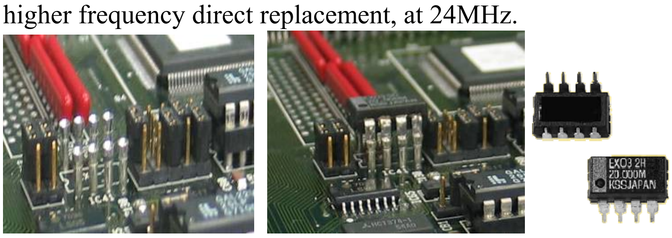


Fig. 9 Picture 8-pin DIP Kinseki EXO-3 20MHz and location on driver board (Photo by CM Heong)

A 20MHz to 24MHz increase is an over-clock of 20%. First tried was on the Theta Motor Controller. Cycle time improved from 250ms to 241ms, an improvement of only 3.6%. It was thought that the new fast theta must be waiting for the other controller axes. When the Z Motor was overclocked to 24MHz, cycle time now improved to 209ms, an improvement of 16%. We are only 4% away from 20%, within measurement error.

V.III.II Overclocking: Oscillator Equivalents

We now need an overclocking program to take us to 30%. This means system clocks ranging from 24 to 38MHz in small increments. There are no Kinseki EXO-3 values over 24MHz. EXO-3 is a Kinseki special: it has 2 outputs, one at full rating (i.e., 24MHz) and another programmable one with 8 possible values. Therefore an adapter PCB is needed to map the nearest wide-range crystal (QXO) to EXO-3 footprint & function. This means a QXO and a binary counter IC like the MC4040B. Luckily, a factory-wide survey of clock settings showed that the second, programmable output is never used. There is then no need to duplicate EXO-3 function, just need to adapt to device footprint. More trials show that we do not even need to wait for a PCB. A QXO can be used directly.

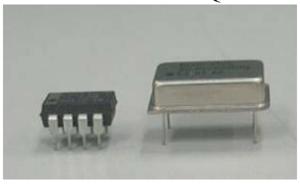


Fig. 10 Picture on the left: EXO-3C. Right: QXO. Note the disparities in size (Photo by CM Heong).

Fig. 11 Above picture shows by bending the QXO leads, it can be fitted in an EXO-3 socket (Photo by CM Heong)

Fig. 12 Picture of QXO in place. Note insulating paper and scotch tape. Note unsatisfactory placement – installation was very difficult. (Photo by CM Heong)

V.III.III Overclocking; Final Version

While bending QXO to fit a DIP8 socket works, it is not Production-worthy. Vibrations from the motors tend to cause it to fall off. Too tight a fit caused it to short out some PCB jumpers. A QXO to EXO-3 adapter PCB was built. Some of the clock values we wanted are not standard "preferred" values. Hy-Q International was willing to custom-make QXO quartz crystal oscillators for RM12 each.

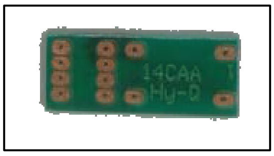


Fig. 13 QXO to EXO-3 adapter PCB (Photo by CM Heong)

V.III.IV Final Overclock Results

Maximum successful over-clock is 28MHz or 40%. The 8 servomotor controllers use different speeds from original 20MHz to 28MHz. No other electronic measures were needed. Heat output was acceptable and stability is good.

V.IV Over-clocking Heating Effect Mitigation

We expected the over-clocking to produce significant extra heat in the motor drive circuit in the servomotor controller. Preparations were made in advance for this, including new copper heat-sinks, drive transistor upgrade to TO-3P, as well as a new thermo-conductive paste. While the temperature rise is measurable, it was not significant, even in the worst-affected board, the theta axis controller. Heat-mitigation measure was quite unnecessary for the servomotor controller.

V.V Other Consequences of Overclocking

Mechanical vibrations were very high. This was later cured by mechanical upgrading. The servomotor controller goes into over-current error sometimes. The worst-case board, Theta controller over-clocked to 26MHz (30% speedup) had the motor current limit increased 320%. PCB temperatures were satisfactory but the servomotors got quite hot. Motors that ran for years failed within 1 month, even when new.

V.VI Overclocked Temperatures

Maximum motor temperature measured was 68ºC which was too much compared to the maximum allowable that was less than 50º C. This was reduced to 52 ºC by reducing the overclock for that. Measured temperature is the motor outer temperature – motor internal temperature must be even higher. Maximum controller heatsink temperature is 80ºC. The motor temperature was finally reduced to 49ºC with compressed dry air-blow and making additional ventilation holes at the plastic cover hood that covers the motors and the bond head as well as the machine back cover.

V.VII Why Over-clock?

It was the first method we tried – the intention was to quickly speed up the motors so that we can concentrate on the mechanical speedup. But despite constant monitoring it did not give trouble for more than 12 months so we decided to deploy it. Over clocking is fast, cheap and easy to implement.

After much evaluation, the Servomotor Controller processor 20MHz system clocks are upgraded to 24MHz for the X, Y, Theta and Z axis for bonding head, plunger and Indexer module. The wafer XY axis table controller remained unchanged.

V.VIII Disadvantages of Over-clocking

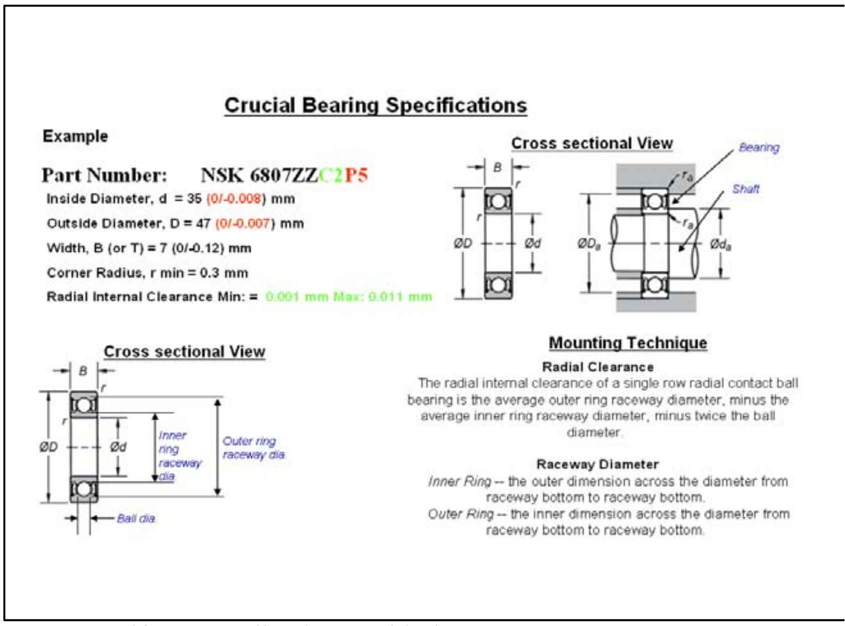
Over clocking exceed manufacturer's specifications due to excessive heat, excessive current, excessive voltage and electro-migration. Electro-migration is the wear and tear in a metal Cu/Au connection due to repeated collisions with electrons of an electric current. Over clocking can lead to instability or even permanent damage of the processor, so an over-clocking program must be carefully monitored.

V.IX Other Effects of Speed-up on Motors

Excessive coil current and heat may result in the reduction of magnetic field strength motor permanent magnets. This will come up over time as a reduction in torque requiring the servomotor controller current limit to be raised further. This effect has not been observed yet. The operating lifetime of servomotor controller boards may be reduced. Again this has not been observed yet. Current motor failure is due to overheating – typically the encoder fails first. The encoder temperature rating is only 50 degrees Celsius, the lowest temperature rating of all the motor components.

V.X Motor Performance Measurement

Comprehensive program for servomotor repair and characterization were made to measure motor torque, current, voltage and vibration offline and these are almost complete. Together with a one-time investment of RM10K for vibration analysis tools give us this capability to



quantify motor vibrations. With these new measurements, we are in a position to make more extensive alterations to the motors, like fluid-fed forced-cooling jackets, better encoders, etc.

VI MECHANICAL MODIFICATION

Although the maximum operating speed was achieved, some major mechanical issues were observed. The servomotors tend to overheat due to the bond head weight (7.9kg). To overcome this issue, the weight has to be reduced.

The bond head vibration at 30% speedup was observed to be very high. This was boiled down to the bearings not being suitable and had to be replaced with the precision type bearings. The Z-slider cage was also not rigid enough and it has to be redesigned to minimize the vibration.

VI.I BOND HEAD REBUILT

For bond head weight reduction, the material that is light and strong to replace cast alloy is Aluminum 6061. By doing this the bond head weight is drastically reduced from 7.9kg to 3.1 kg. Listed are the parts that have been redesigned and fabricated by using Al 6061.Y table bond head assembly, Y lead screw nut assembly, Theta axis mounting block and Z-axis linear bearing mount assembly.

Table 2 Material properties comparison between Cast alloy and Al6061 [Ref 5]

Properties	Cast Iron	Al 6061
Tensile strength MPa	370	130 – 270
Yield limit	240	65 – 225
Elongation %	12	7 – 15
Specific Gravity	7.1	2.70
Resistivity at 20° C μ.Ω.m	0.50	3.3
Heat conductibility	36 Wm-1K-1 at 50° C	200 Wm-1K-1
Young Modulus MPa	170 000	69 500
Average expansion coefficient at 20° C	10.5.10-6 m/m° C	23.4.10-6 m/m ° C

VI.II BOND HEAD VIBRATIONS

Vibrations are the effect of rigidity and clearances. To reduce vibration, structure rigidity needs to be improved by material change or redesign the parts/geometry. Tolerances and fitting clearances between parts need to be as tight as possible. There is a high vibration at the bond head at more that 130% cycle speed. Solutions are to redesign the Z- axis slider cage and to use precision class 5 (high speed) bearings. The machine mechanical overhaul procedures are improved in conjunction with integral accuracy measurement.

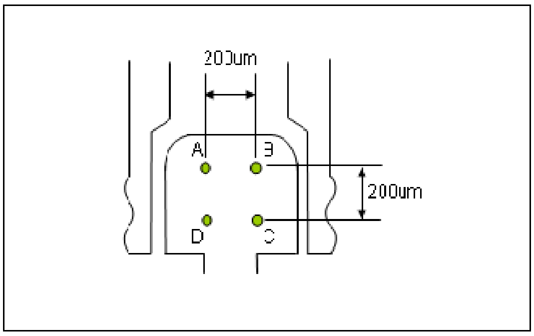


Fig. 14 Crucial Bearing Specification. (Diagram by Yuserizal)

VI.III BOND HEAD ACCURACY MEASUREMENT

Fig. 15 Four points of lead frame flags/island. (Diagram by Yuserizal)

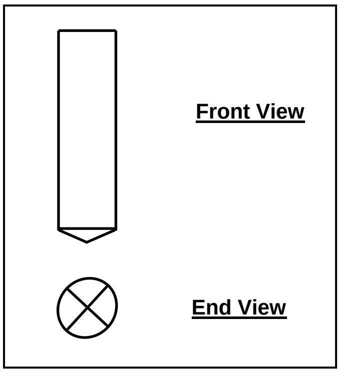


Fig. 16 Pin Collet (Diagram by Yuserizal)

We established a measurement methodology to verify the bond head rigidity and accuracy. A diamond-shaped tip was designed to be installed in place of the pickup tool. This was used to mark four points on each lead frame flag/island. We used the existing PRS vision system to make the setup measurement in units of servomotor encoder counts. Once enough points have been made, we dismounted the lead frame and performed the actual measurement using high-powered microscope. Each set of four measurement points were compared for positional accuracy and repeatability.

The accuracy achieved was well within machine ex-factory specification and we believed this is an improvement of existing machine accuracy. This represented improved method for verifying bond head accuracy and repeatability.

VII OTHER METHOD FOR SPEED-UP

One probably better method of speed-up is to modify the machine mechanical layout (by reducing bond head travel stroke). This involves major changes in software motion kinematics profile. This option is to be explored at a later date.

VIII CONCLUSION

Objective to improve legacy die bonder speed more than 17% is achieved. The stable machine speed up is gained from over clocking the Servomotor Controller processor board from 20MHz system clock to 24MHz System for X,Y, Theta and Z axis for Bonding Head, Plunger and Indexer module. The system clock for the x-y axis Wafer Table is unchanged at 20MHz. Total speed up modification cost was just RM13, 940.96. Since the realizable die bonder speedup is 30%, the bottleneck has shifted to the wire bonder. This has become the focus for future development.

REFERENCES

[1] Renesas Inc, “SH7032, SH7034 Hardware Manual”

[2] Renesas Inc, “SH-1/SH-2/SH-DSP Software Manual”

[3] Keyence Inc, “2006 Sensors Vision Measurement & Microscope”

[4] NSK Ltd 1989 CAT. No. E1102f 2008 E-10, “Rolling Bearing”

[5] Rob Ramsdale “Engineers Handbook”, EngineersHandbook.com http://www.engineershandbook.com/Tables/materials.htm

Yuserizal Mohd Noor is a Senior Engineer (Mechanical Design) in ON Semiconductor Inc, Seremban Malaysia. His research interests include high speed automation. He has a degree in B.Eng Mechanical majoring in Aeronautics from the University of Teknologi Malaysia, Johor Bahru.

Heong Chee Meng (M'95-SM'04) is a Senior Staff Engineer in ON Semiconductor Inc, Seremban Malaysia. His research interests include embedded computing, Linux and electronics. He has a degree in engineering majoring in electronics from the University of Malaya, Kuala Lumpur

Harmit Singh is a Staff Technical Specialist in ON Semiconductor Inc, Seremban Malaysia . His research interests include high speed automation,upgrading equipment and preventive maintenance. He has a Higher Diploma in Electrical/Electronics Enginering from Tafe College, Seremban.

Tan Yuet Chuan is a front-of-line Process Engineer in On Semiconductor Inc, Seremban. He graduated from University of Nottingham Trent in 2006 with a bachelor degree in electrical and electronic engineering. Currently, he is doing research and development for copper wire bonding.

Emelia Khamis (M'08) was born in Muar, Johor in Malaysia. She works in ON Semiconductor Inc, Seremban Malaysia as an Electronics Engineer. Her research interests include Electronics and Linux. She has a B.Eng from the Univeristy of Malaya, Kuala Lumpur.

Siva kumar S Nadarajan is Head of Equipment Engineering group in ON Semiconductor Inc, Seremban Malaysia. His research interests include Equipment efficiency improvement and preventive maintenance. He has a degree in Science majoring in Physics from the University of Madras, India and Master of Business administration from the University of Hertfordshire, UK.