Electronics Packaging

by Dennis L Feucht

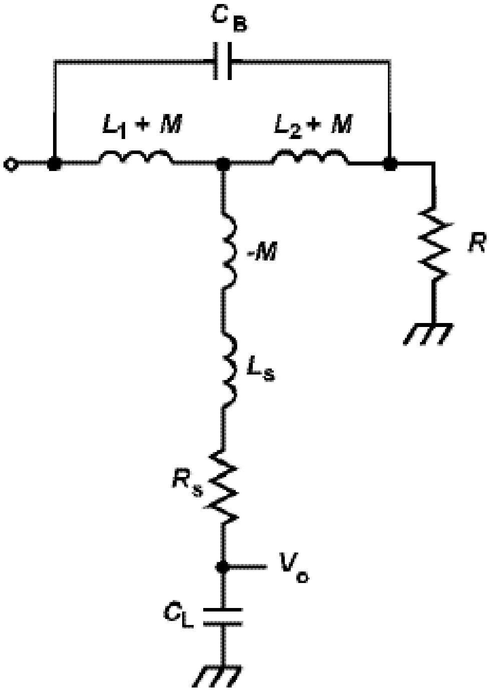
Electronics packaging is not central to electronic design, but it has a disproportionate effect on the technology. The overall trend is toward shrinking volume and this has its relative merits. Several consequences are explored here, beginning with the engineering design and expanding to the problems that engineering design is intended to solve.

IC Packages

The driving factor in the reduction of electronics packaging is the reduction of IC packages, both in size and number. Size reduction is, in part, due to shrinking silicon area, allowing the chips to be put into smaller packages. IC shrinkage has several circuit consequences: as transistor and other circuit component dimensions are reduced, parasitic elements are also reduced in value. Smaller junction capacitances and terminal inductances allow transistors to have a higher f_T, resulting in higher amplifier bandwidths. Shorter interconnections of components reduce wiring inductance and wire-to-substrate capacitance.

In the 1970s, the leading companies in wideband amplifier design were mostly the test and measurement (T&M) instrument companies such as Tektronix and Hewlett-Packard. Tek led H-P in oscilloscope bandwidth with the introduction of a vertical plug-in accompanying the new 7904 mainframe. Combined, the vertical system achieved a 500-MHz bandwidth -- quite a feat at the time. Tek's vice-president of engineering, Bill Walker, had pushed for Tek to set up an in-house IC fab facility which, by this time, was an obviously good idea. (Walker later became president of Tek.) Tek had the fastest commercial transistors on the planet, with an f_T of 7 GHz.

One of the leading vertical designers, John Addis, wrote an article for *Electronics* magazine revealing a clever idea he had of using IC bonding wires as inductors to form a T-coil, a passive network (described in *Analog Circuit Design* at http://www.innovatia.com) that took inductive bandwidth extension, or peaking, to twice that of series inductive peaking and nearly three times that of the uncompensated RC circuit. A T-coil interstage coupling circuit is shown below, where the input on the left is typically a transistor collector output node.



L_1 and L_2 correspond to the IC bonding wires, brought out from two pads to a single pin. The inductors are magnetically coupled, with mutual inductance M. The additional pin inductance, L_s, is also part of the circuit. R_s is the series input resistance of the next transistor stage, and C_L is its capacitive loading. The bridging capacitor, C_B, generally has a small value, suitable for monolithic integration.

Tektronix also pioneered high-speed packaging, with a *spider* package: a thin, molded disk of plastic in which the die was embedded, radiating pins forming a square outline for the socket on the board. The corner pins were longer and wider than those in the center of the row. This package was used well before the PLCC, with its four sides, and was a through-hole forerunner of the quad flat pack. LCCs were also in use in Tek products before the concept spread into the industry. This was due, in part, to vertical integration at Tek. An entire building was dedicated to ceramics, and in the vacuum-tube era, Tek scope wiring was known for its ceramic terminal strips. The mechanical integration of cooling fan, heat sink, and IC package commonly used for microprocessors today was also anticipated years before in Tek scopes. One heat sink that clipped onto the top of a power-dissipating vertical amplifier IC had a matrix of round, vertical pins, anticipating the newer, thermally-efficient pin-matrix heat sinks. New packaging ideas aren't always as new as they seem.

Now the dominant trend is to get rid of the package, resulting in solder-bump ICs. This trend is favorable for higher speed and minimization of circuit noise. However, it has necessitated changes in how engineers build prototype circuits. For through-hole, a prototype can be built on the bench by an engineer with ordinary eyesight and dexterity, using a soldering iron, solder, needle-nose pliers, diagonal cutters, wire-stripper, and protoboard. Pin spacing of 0.1 inch allow easy access to the pins for soldering. Even the 50 mil spacing of SOICs is workable. In some respects, it is the optimal packaging for manual prototypes, for not only does it increase board IC density by about four times, it also results in both parts and wiring on the same side, making wire tracing somewhat easier. By flipping the SOICs over and attaching them to a ground plane with a spot of glue, the elevated pins are then available for magnet-wire interconnection. If an IC fails or is to be replaced, however, the entire IC must be unsoldered. With through-hole packaging, the IC is pulled out of its socket and easily replaced. ICs do not fail that often, and the ones that do, or have many pins, can sometimes revert to through-hole socketing.

With pin pitches less than 50 mils manual prototyping becomes difficult. Magnifying glasses might help, yet no longer can even the slim-tipped irons keep from bridging solder to adjacent pins. Van der Waals forces are relied upon to orient the IC and its pins as they float on liquid solder above the tiny pads. Melting of the solder is accomplished by either an infrared heat source or hot air. In both cases, the IC itself is elevated to the melting temperature of solder. No longer are the soldering tools $30 items. And with a board of any complexity, the parts are aligned on the pads with an automated pick-and-place machine. Protoboards are long gone (except for the kind that adapt tiny ICs to through-hole pad spacing), and the board is built *for* the engineer, not *by* the engineer.

Once built, board changes -- which have been a common feature of design development -- are also difficult. This changes the style of design, pushing it in the direction of being simulation-intensive. The changes are made in the simulation instead. The resulting board becomes a unit of electronics, a subsystem-level component that is not modified, only replaced by a modified board design. Some engineers who grew up with the through-hole style of engineering find that tiny, surface-mount components take much of the fun out of design. Packaging changes have changed the nature of the art.

Product Shrinkage and Fragility

Until the 1970s it was not uncommon to find electronic products packaged partly in wood. Even the 1960s still had hi-fi or stereo sound systems integrated into a single wooden cabinet, following the furniture motif. Plastic displaced wood and metal, and products became smaller and lighter. It was in the 1970s that respectable portability in electronics instrumentation and consumer products began to appear. Hand-held instruments came from Fluke, and Tek had a portable-scopes product line; scopes that could, by design, be slid underneath an airplane seat. Now Fluke, Tek, and others have hand-held scopes in rugged plastic packages.

Consumer products have also shrunk, notably the telephone in the form of mobile, or cell, phones. With shrinkage has come fragility, for the connectors have also shrunk. Smaller connectors are not made of any new super-strong materials and consequently are more fragile. With surface-mount boards, these products become a unit of technology and when they break, are simply discarded. This poses a problem when miniaturizing; the advantage of smaller size must be weighed against the disadvantages of fragility and product life and wear.

Computers have really shrunk and illustrate that human factors pose limits to miniaturization. The keyboard is still preferred over PDA styluses, yet it is not hard to imagine that the electronics for a capable portable could itself be packaged for shirt-pocket size. It would certainly be desirable to be able to carry around one's library of files and other information, project documents, and e-mail in one's shirt pocket or around one's neck. The problem is the human-machine interface. The conditions appear to be right for serious efforts in this area. Speech interfaces have been around for some time but have never really caught on, especially in locales where there is a high density of computer users sharing the same acoustic medium. The creative inventor of the Forth computer language, Charles Moore, invented and built a hand-held keyboard with 5 buttons. That gives 32 distinct states, which codes most of the commonly-used keyboard characters. Using double-clicks or other time sequencing, the states can be multiplied to include the full 104-key keyboard. Like touch typing, one could then learn to speed-type on such a keyboard, and in the hand of one's choice. With a five-finger keyboard and touch screen, perhaps the shirt-pocket computer can debut.

Going beyond this are projects at MIT and elsewhere to build electronics integrated into clothing. Piezo-actuated LEDs in tennis shoes are a frivolous start. So are RFID chips sewn into clothing. The computer and clothing industries might merge in time -- a rather unforeseen economic development. In the interim, the shirt-pocket computer could easily migrate to become a helmet or glasses computer. When organic semiconductors appear in the form of flexible sheets suitable for making clothing, the helmet or other artifices could then disappear.

Ultimately, computers become prosthetic devices in the form of brain transplants. Before that happens interfaces to clothing computers might consist of implantable biochips. With parallel growth in networking, the extent of machine-human integration takes packaging well beyond present conceptions into the realm of speculation about the kinds of societies that would result -- no less what states of mind humans in them would even have. When a component fails, does the integrated human get thrown away with the machine?

EMI and Radiation Susceptibility

In the 1970s, the USA and Soviet Union carried out a joint space mission that linked Apollo and Soyuz capsules. The idea, as expressed at the time, was to have some compatibility between the manned vehicles of the two governments that were flying in space, in case one had a mishap and had no additional spacecraft available to effect a rescue. A rather complicated mechanical docking adapter was jointly developed to allow for this.

What took some American technologists by surprise was the crude level of technology in the Soyuz. The electronics was dominantly vacuum tubes, in miniature form similar to Nuvistors. In my technical youth, I remember smirking about this -- about how far behind Soviet electronics technology was. Not much later, I read some assessments of US missile vulnerability to ionizing radiation. The solid-state electronics in the Minuteman missile, for instance, had a crowbar circuit that activated across the guidance-system supply upon detection of a neutron wavefront. The supply was shut down immediately for a calibrated amount of time and when restored, this off-time was factored into navigational corrections. I wonder if the bulky, antiquated Soviet tube circuitry even required such a precaution; probably not. For a while, there was some concern that the infrastructure of solid-state America could be shut down by electromagnetic-pulse (EMP) bombs, leaving the buildings and everything else intact but dysfunctional.

The mitigating factor is that back then, the lambda, or basic quantum unit of on-chip sizing, was huge by today's distances, making ICs less susceptible to electromagnetic interference (EMI) and electrostatic discharge (ESD) damage. Packaging of electronics systems is correspondingly affected, for it must be increasingly effective in shielding against both. In the days of metal packaging, the metal itself provided EMI and ESD shielding. With plastic boxes, metal has been retained but in miniaturized form. Zinc is sputtered or sprayed onto the insides of plastic cabinets. The thin layer is then interfaced with a clip or bolt to the circuits within. Metalized plastic does not offer the shielding performance (due to thinness) that the sheet-metal cabinetry does, nor does it protect externally against an electrically-charged human. To cope with these deficiencies, ESD protection has migrated on-chip while EMI protection is lessened by smaller size. As size shrinks, the affecting frequencies increase and such radiation becomes more beam-like and easier to protect against than pervasive, low-frequency electric and magnetic fields.

Closure

Packaging is often regarded as an afterthought in electronics, though this quick look at the wider consequences suggests that it has an enormous impact on the direction and style of electronics design, no less on the social impact of the evolving man-machine interface. For a really mind-blowing extrapolation of the possibilities, I point you to Carnegie-Mellon University Field Robotics Center mobile-roboticist Hans Moravec, one of the leading roboticists of all time, and his book *Mind Children*. Hans is waaay beyond computerized clothing!