TECHNICAL INFORMATION

A PASSIVE COMPONENT APPROACH TO FASTER, BETTER & CHEAPER

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Abstract:

Much of COTS focus is on systems and hardware resulting in secondary emphasis on component level solutions. Yet new developments in design and testing of passive components are essential to achieving the goal of "Faster, Better, Cheaper."

This paper describes product development in design of passive EMI filters and circuit protection devices that are enabling these goals to be met. Component level testing is also essential, as once in situ, it is rarely possible to stress individual components to the necessary acceleration levels to ensure optimum application reliability.

Finally, sourcing is also considered – with the prevalence of EDI transactions in the commercial sector the "Shelf" in "COTS" can be a virtual entity; some guidelines for design engineers are also discussed.

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COTS vs MIL – Are We Agreed?

COTS is literally defined as standard catalog material, end of story. This standardizes procurement but does not protect the application. Mil standards protect the application (and hopefully address obsolescence), but are restrictive as emerging technology cannot be easily integrated. To address this, many manufacturers have developed initiatives to define a middle ground that either enable supply of military grade products from commercial facilities or extend product offerings beyond QPL listings in established Mil manufacturing locations.

These go by a number of names – COTS-plus, Mil/COTS, etc. These products typically offer quantifiably higher reliability (Weibull test, extended burn-in, etc.), as opposed to products differentiated by other generic terms (ruggedized, industrial grade, etc.) that may not. The key is to SPECIFY the requirement and match the part to the application.

Component Level Design and Development

“Passives” is a term that encompasses more than capacitors resistors, inductors, etc. Circuit protection devices in particular are becoming more critical to Hi-Rel designs. Also, the demands on parametric performance are increasing, with ESR, ESL (Equivalent Series Resistance and Inductance respectively), EMI (electromagnetic induction) and ESD (electrostatic discharge) requirements becoming increasingly specified. Underlying this, the demand to reduce size and cost, while increasing functionality, continues unabated.

Manufacturers are responding on a number of levels: by downsizing by increasing CV (capacitance / voltage product or reducing package size), or by increasing circuit functionality.

Downsizing – Increasing CV

For tantalum chips, there are relatively few degrees of freedom for downsizing – the dielectric constant (K) and dielectric thickness per volt for Ta_2O_5 are essentially manufacturing constants. The continual improvement in CV (capacitance / voltage product) over time is primarily due to the ability to produce and process Ta powder with decreasing particle size distributions.

Low CV (8000 CV/g) | **Medium CV** (18000 CV/g) | **High CV** (27000 CV/g)

Magnification x 4 K

This results in increased surface area within a given unit volume and hence increased CV / cc, without any changes to dielectric properties. The net result is that the majority of ratings now available go beyond the original QPL listings, so that alternative means of specifying them to required reliability levels are required.

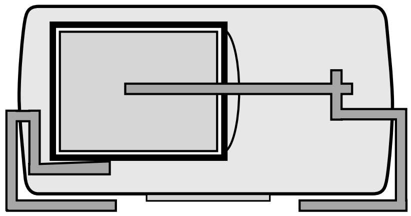
For ceramic multilayer chips (MLC) there are more variables – the different classes of dielectric and their temperature, voltage and frequency characteristics are well documented – but additional capacitance gains are being made within any given class by dielectric formulation advances using additional layers, or thinner dielectric laydown for low voltage applications.

Downsizing – Reduced Package Size

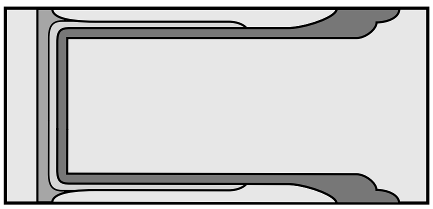
Very often, packaging itself (leadframe, molded body, margins, etc.) adds to the size and weight of a component. For tantalum chips, as the capacitor element is downsized as a result of powder technology, a given rating can be inserted into a smaller (and lighter) case size. To get to the next level, alternative packaging technology can be used to eliminate leadframe and molding and enables production of 0402 size tantalum chip or much increased CV versions of molded 0805 (EIA 2012) and 1206 (EIA

3216) equivalent sizes. For MLC, reduced margins and increased layers have promoted downsizing, and in the commercial sector, the shift to small size 0402 / 0603 usage is accelerating.

Molded Construction (0805)



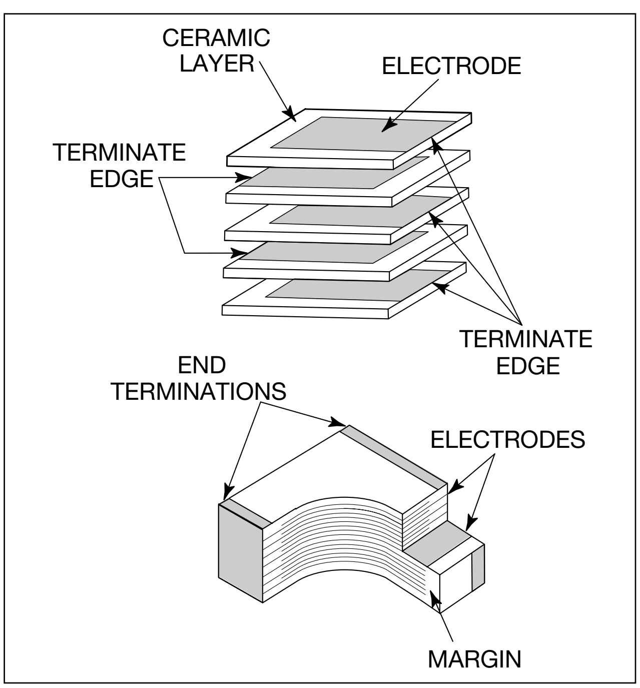
MicroChip Construction (0805)



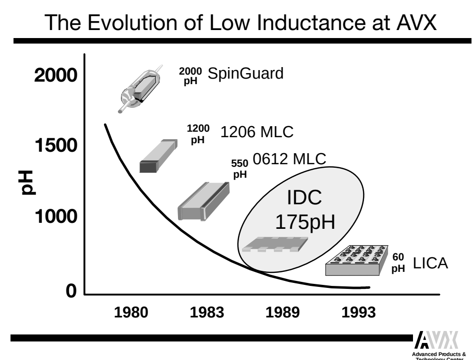
Parametric Improvements; MultiFunctionality

Many commercial applications are driving parametric improvements to achieve lower costs – if you are using a high CV tantalum for its low ESR in a capacitor bank, a 20% lower ESR part will allow a 20% reduction in component count. MultiFunctionality achieves the same goal – if you can have one component with dual characteristics, you can reduce placement costs and PCB real estate.

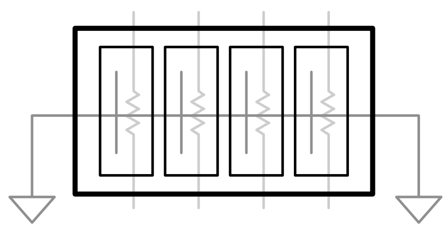
Looking at multilayer ceramic chip design, there are many possible permutations that can enable this when both the geometry and materials are considered.



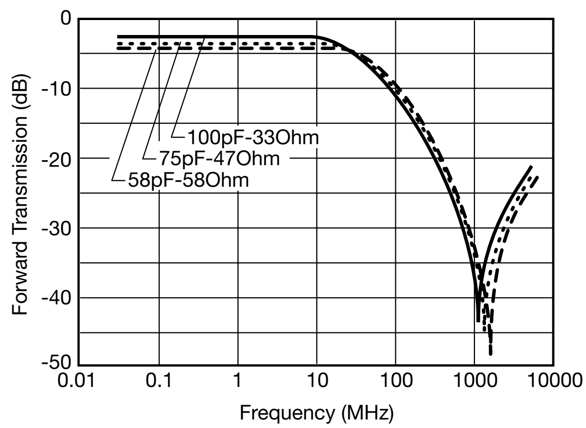
First of all, consider the external geometry. ESR has long been a staple requirement for power supply filtering, but low ESL is becoming more critical for high speed decoupling. Ceramic MLC chips have intrinsically low ESR compared to leaded devices, due to the smaller external current loop when connected to the PCB. By terminating along the side, signals can pass more freely with ESL reduction. This is the basis for the “reverse geometry” LICC (Low Inductance Chip Capacitor). The next step is to change the internal geometry – by subdividing the electrodes and connecting pairs alternately in VIP (via in pad) configuration to the power plane, cancellation of current loops occurs and inductance is effectively halved again. This is the basis for the IDC (interdigitated capacitor). The lowest ESL currently available comes from the LICA® (Low Inductance Capacitor Array) where embedded electrodes give cancellation in two dimensions.



End terminations linking lengthwise to electrodes in the reverse geometry package give rise to feedthru capacitor families, including low pass filters, which are essential for low cost (non-bulkhead) EMI solutions.

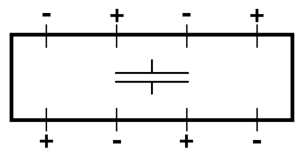


HP8753 Analyzer w/50 Ohm Calibration

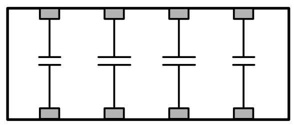


Another variation on the “interdigitated” theme is to retain the external termination configuration and subdivide the electrodes internally to give multiple discrete capacitors – the capacitor array – which in turn leads to IPCs (integrated passive components):

Interdigitated Chip:

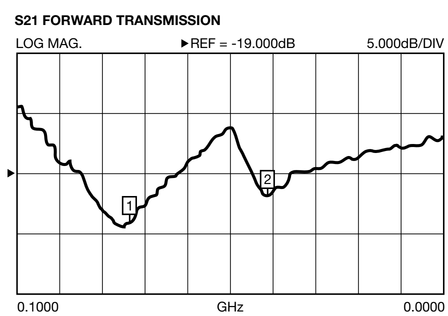


Capacitor Array:



The next degree of freedom is the electrode stack geometry. This can be manipulated within a standard two-terminal configuration to give dual characteristics in frequency response – essentially a package with one bulk capacitance characteristic but with two discrete resonances – acting as a parallel pair of dissimilar capacitors. Control of the geometry enables these resonances to be tailored to predetermined frequencies, giving the basis for the DRC (Dual Resonant Capacitor), for application specific designs in dual band cellular. In Europe, triple-band is emerging, and, needless to say, there is already a TRC on the market.

Typical Insertion Loss (S21) for 0603 DRC



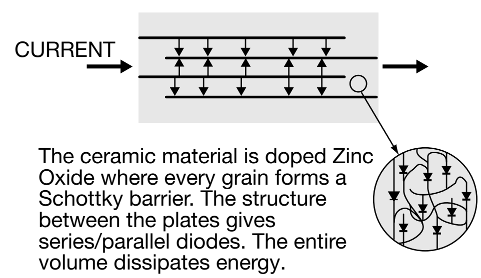
By using different materials, other sets of functions become available. Using resistive electrode material in conjunction with established stack geometry and alternate dielectric materials, precise capacitance and resistance combinations can be achieved in a single co-fired two-terminal device. This is the basis for the RC chip (|Z| chip™ family) specifically designed for ac bus terminations. Following the same route of subdivided electrodes leads to the |Z| array™ and low pass filter families.

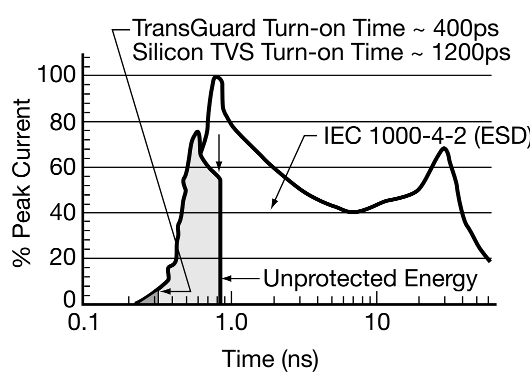
Circuit Protection Devices

For Hi-Rel design, circuit protection can often be more cost effective than over-design or redundancy. Two technologies gaining momentum in this area are TVS (transient voltage suppression) and fusing.

Silicon based TVS devices have been established for some time in the SOT 23 diode package. More recently, the zinc oxide based, bidirectional TVS device has been used in more critical applications.

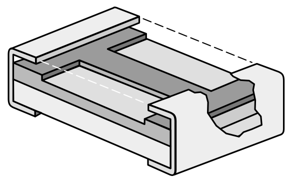
This technology, where the transient energy is dissipated through the grain boundaries in the bulk of the device, rather than across a single junction, has many other advantages. It gives extremely high repetitive strike capability, fastest response time (typically 400ps turn-on), high inrush current capability and defined capacitance values that enable dual usage for EMI / RFI (electromagnetic and radio frequency) induction filtering. While passive component failure rates can be very low (ppm levels for commercial products under standard operating conditions) many passives have short circuit failure modes which can present problems in mission-critical applications. From the thin film





family of high-Q capacitors, inductors and directional couplers, the thin film fuse has been developed for this type of application. It has very precise fusing characteristics (determined by film thickness and geometry) allowing fusing in very short time periods (<5 secs) after a fault current has developed, while passing normal dI/dt pulses associated with turn-on. Package sizes are small (to 0805) and it is not necessary to deploy on a 1 for 1 basis with all passives, just critical locations or strategically amongst capacitor banks.

Thin Film Fuse:



Medical – The Other Hi-Rel Application

All emerging component technologies are being manufactured and tested in accordance with best commercial practices, and are able to document improved reliability as part of continuous improvement programs. However, all commercial product has reliability measured against 60% confidence limits (equivalent to exponential level assessment). For lot-level assessment, additional levels of assessment are needed, and these cannot be defined in a strictly Mil framework as many of the components discussed above are not yet incorporated.

If we state that the idea behind COTS-plus is to specify a Hi-Rel part beyond QPL listings without recourse to individual SCDs, then it is well worth looking at developments in the medical sector in recent years. There are some differences between medical (human implantable systems) and military / aerospace applications – deployment temperature being an obvious one – but there are more important similarities. Although application temperatures are benign for a pacemaker, the first hurdle of having the part survive a surface mount process is common to all SMD assemblies, whether hybrid or PCB based. Beyond that, there are many parallels, such as operating continuously with little parametric shift with low leakage / IR levels (pacemaker); having an instant-on requirement to handle high current densities (defibrillator) and resistance to external EMI / RFI (all). Beyond both of these considerations are size and weight – the smaller the device, the less collateral cost in deployment – whether in terms of major surgery for implants or payload costs.

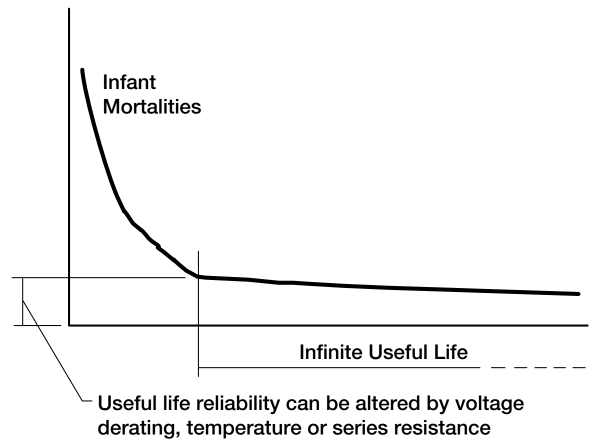
The medical sector provides its own success story – they have been first to qualify new technologies (e.g. extended ratings, 0603 tantalum microchip, IPCs, etc.) and apply in Hi-Rel designs to common reliability standards. The result has been continual hybrid downsizing and down weighting (an important factor in humans as well as payloads) and reduced device and deployment cost. For a "typical" pacemaker, device costs have dropped $12k to $4.5k over the past 10 years. For defibrillators, typical costs have reduced from $35k to $25k over the past year. More importantly, reduced size means installation can be via chest rather than abdomen, resulting in a less stressful procedure and halving installation costs from $10k to $5k.

In addition, reduced hybrid space can mean more battery space, giving longer life and moving more toward "fit and forget" deployment.

The level of miniaturization now possible is also enabling new implantable technologies – nerve stimulators, cochlear implants, insulin pumps, etc.

Component Level Test – Lot Level Assessment

The question is – What is the recipe for achieving this? Reliability is the key consideration. For many passive components, burn-in and overstress testing (e.g. surge or Hi Pot test) are the most important means of eliminating infant mortalities from a population. The tantalum chip is a good example to consider. The steady state reliability characteristics are well understood and conform to a Weibull open bathtub curve:



The Weibull test is a statistically monitored 40 hr burn-in – it measures the shape parameter of the curve and the final release point reliability level – and is the basis for all military and medical qualifications. For dynamic conditioning, surge test can also be applied testing either at ambient or low and high temperatures (-55°C / + 85°C).

Once the "infant mortalities" are eliminated, the lot will continue at its optimum failure reliability level. This level has to be within the specified requirement (typically B or C level, 0.1% or 0.01% per 1000 hours respectively at 90% confidence) or the lot is downgraded.

For a "COTS-plus" type product, additional conformance tests (group A, group C) normally required for Military can be skipped – these do not add to reliability once Weibull is complete, and costs can be reduced.

Circuit design is also important. Given that COTS-plus opens up availability to ratings beyond the QPL, additional reliability can often be achieved by design rather than increased testing. This is done by voltage derating. Once you have a Weibull tested lot (90% confidence), by using a higher voltage rating for a given application voltage, the reliability gain can be better (and cheaper) than specifying C Weibull grade. This usually cannot be achieved with QPL product due to rating limitations.

For all applications, component level assessment cannot be emphasized strongly enough. Using purely commercial components and attempting to upscreen at the hybrid or system test level will not work. Most components require accelerated voltages far in excess of their application voltage to ensure early life fails are culled from the population. Failure to do this may mean low risk in standard applications (commercial parts do achieve low ppm failure rates), but in applications that may require an "aggressive" stage in their duty cycle (current or voltage pulse, etc.), component pre-screening is essential.

For tantalum chip, Weibull and surge test are major considerations in any mission critical application. Because the dielectric operates at very high electric stress, small overvoltages equate to high acceleration factors. For most ceramic chips (16v ratings and above), the overvoltage capability is high compared to application voltage. As a result, statistical monitoring is usually not a requirement, and burn-in is based on an exponential model.

The footnote to this is that once the final failure rate is calculated and within requirement, the failure mode can then be addressed by the use of circuit protection devices discussed above.

Sourcing

One thing we rarely discuss is the "S" in COTS – the shelf itself. The assumption is that by sourcing commercial parts, there will be a readily available source. This is not always the case – an example being the upside now experienced in the computer / cellular sector. This has impacted a number of product families. Major OEMs' contract manufacturers operate largely by EDI – scheduling product to forecast and accessing the component manufacturers capacity. On an upcycle, this affects leadtime, and any non-scheduled orders are impacted. Medical manufacturers typically have orders forecasted well in advance, but the sporadic nature and low volumes associated with many military / avionic programs can put this sector at a disadvantage.

Fortunately, sourcing from manufacturing locations dedicated to the production of Hi-Rel or COTS-plus devices will mean that any disruption will be minimized. However, the key for any low volume or intermittent program is to engage with a preferred distributor who can help with scheduling and help maintain your own – real or virtual – shelf.

As a final note, it is important to remember that while this paper has focused on new product availability, there is a core set of military items (leaded and surface mount ceramic, tantalum, RF components) that remain available with no plans for obsolescence.

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(4) AC Termination for Signal Busses
Ben Smith (AVX)

(5) Reliability Management of Tantalum Capacitors
Chris Reynolds (AVX)

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