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TANTALUM-NIOBIUM INTERNATIONAL STUDY CENTER

PRESIDENT'S LETTER

Dear Members and Friends,

As we enter 1997, it is useful to reflect on events that happened to our industry during 1996. As one who has been involved in two sectors of the tantalum industry, raw material supply and its processing, for almost twenty years, I cannot dispute the statement made by Dr Korinek during the Greenville meeting that 1996 was a year of major structural changes in our industry, resulting in consolidation and globalization of the different branches of our business.

As customers demand higher and higher performance in the products we sell, the cost of developing and meeting such demands (not to mention environmental costs) made it extremely difficult for small companies to participate in this business. After all we are not selling commodities like copper or zinc, but performance. This brings me to the question of technology - our present technology is based on one that was developed in the 1950s and it is stressed to its limits to comply with the demands of the electronic industry of the 1990s. I wonder how far the present know-how can be used to accommodate this tough requirement of the electronic industry and it is only a question of time before we have to upgrade the technology. This problem must be addressed with vigor as we approach the new millennium.

Now back to the present business:

1. The Executive Committee meeting will be held in the morning of April 22nd 1997 in Brussels, followed by an informal meeting with the members and a luncheon. All delegates of member companies are invited.

2. Plans for the General Assembly in Xian, China, October 5th to 8th 1997 are progressing well and should be finalized during the April meeting in Brussels.

Yours sincerely,

S.S. Yeap

SUMMARY

INFORMAL MEETING

An informal get-together will be held in Brussels, at 40 rue Washington, on Tuesday April 22nd 1997. Following the meeting of the Executive Committee in the morning, other delegates will be invited to join the Committee members for lunch and general discussion. Letters will be addressed to the voting delegates of the member companies, anyone else who would like to join the group should contact the Secretariat without delay.

XIAN, CHINA, OCTOBER 1997

The T.I.C. will organise a meeting based in Xian from October 5th to 8th 1997, including the Thirty-eighth General Assembly on October 6th.

Registration and a welcome reception are planned for Sunday October 5th. On Monday the formal business of the General Assembly will be followed by a programme of technical presentations focussing on tantalum and niobium in China, and also covering other aspects of the industry involving these metals. In the evening all participants will be the guests of Ningxia Non-ferrous Metals Smelter and the Non-ferrous Metals Society of China, our hosts, at a banquet dinner.

A tour of the plant of Ningxia Non-ferrous Metals will be organised on Tuesday October 7th.

On October 8th it is intended that there should be an opportunity to see the terra-cotta army, and study tours including sightseeing will be offered in the next days. Special arrangements with a Chinese travel agent will be made to help delegates reach Xian, and the agent will also be able to assist them with the rest of their travel programme.

Reservations and pre-registration will have to be completed well in advance of the event: invitations and full details will be sent to member company voting delegates in due time, others interested in attending should contact the Secretariat as soon as possible.

APPLICATIONS OF CERAMIC, TANTALUM AND ALUMINUM CAPACITORS

by Mr John Prymak, Kemet Electronics, given at the T.I.C. meeting in October 1996

WHAT'S AVAILABLE?

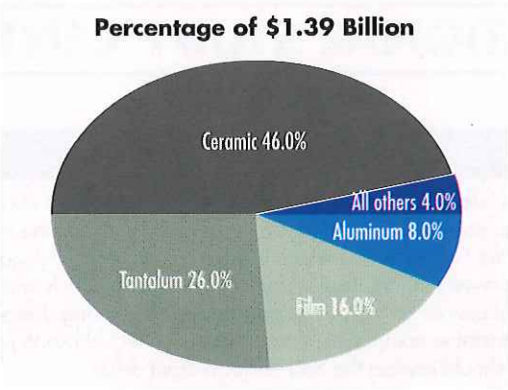


Figure 1 : 1991 EIA capacitor sales

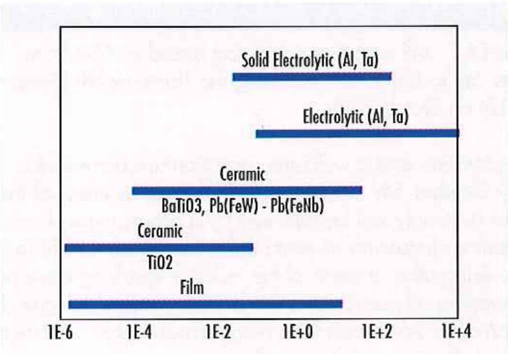


Figure 2 : Electrostatic capacity

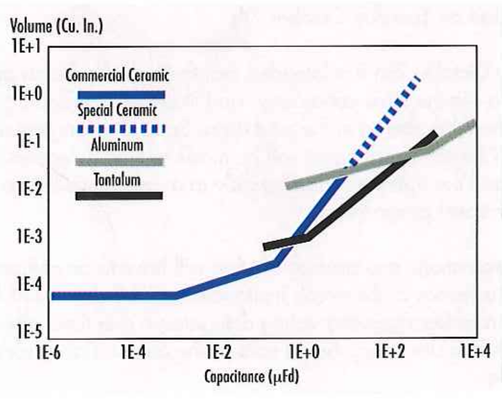


Figure 3 : Capacitance vs. volume

Based on recent market data, the four main types of capacitors are ceramic, tantalum, aluminum electrolytic, and film; and these are listed in relative magnitude of sales (Fig. 1). What determines which type of capacitor is best suited for any application? If one were to decide the type used based on available capacitance range, there are many areas of extensive overlap where aluminum electrolytics, tantalum, ceramic and film capacitors all offer devices that supply the desired capacitance (Fig. 2). If weight and size were the determining factor alone, then tantalum would dominate as it has the greatest capacitance per unit volume, with film the least volumetric efficient (Fig. 3). Cost per unit of capacitance would show the aluminum type to be the best with ceramics and film capacitors to be worst. Yet the factors that determine greatest usage are a combination of those previously listed as well as the applications' requirements. There are small capacitance applications that preclude usage of tantalum and aluminum, as there are large capacitance applications that preclude the ceramic and film types. There are applications that have switched to surface mount manufacturing which have been responsible for the enormous growth of ceramics.

GRANDFATHER ISSUES

• Power Applications	• Aluminum
• Small Signal Processing (Decoupling, Bypass, Coupling)	• Film, Ceramic
• Large Capacitance (Power Entry, low Current Hold-Up, low Frequency Bypass)	• Tantalum
• High Frequency, High Current (Oscillator, High Frequency Bypass)	• Film

Figure 4 : Applications governed type - 'grandfather' controlled

There are many applications of capacitors that have been constant for a number of years. These "grandfather" applications have absorbed elemental changes in basic circuit design that have allowed maintaining type allegiance (Fig. 4). In many cases, these changes have required some variation of the capacitor usage to new and improved products, to multiple capacitors in order to achieve newer and more stringent requirements. It seems that the last and final change dictates a change in capacitor type in order to achieve operational success of the circuit.

From fifteen years ago, the markets for the various types of capacitors could appear to have become "niche" type markets, where the applications would definitely dictate the type. In power applications, the aluminum electrolytic reigned supreme. In small stable capacitor requirements, the film capacitor held firm. In small signal coupling applications, the ceramic capacitor seemed to fit the bill best. These were carried as "grandfather" fixations that held designers' allegiances to stay with these types in these applications because they always worked before, and there was extensive knowledge of the product and the methods of insertion.

APPLICATIONS

There are really five main areas of applications for capacitors:

1. decoupling
2. filtering
3. coupling
4. timing & wave-shaping
5. oscillating

Oscillating circuits are special circuits that may be found in many devices, but their numbers are rather limited. The capacitor usage here is small compared to the total market and it tends to use smaller value ceramic and film type capacitors.

Timing and wave-shaping circuit applications are again rather insignificant in the overall market scheme, but they are apparent in our everyday lives (Fig. 5). They take advantage of the simple RC (resistor in series with a capacitor) response which can dictate the timing that it takes for the capacitor to charge to a given level. These are easily manipulated by varying the resistance in series with the capacitor, as with the pulse wiper control in automobiles: increase the resistance and the time to charge (time between pulses) will increase, and decreasing the resistance decreases the time to charge. Depending on the timing periods and stability requirements, this market is open to all types of capacitors.

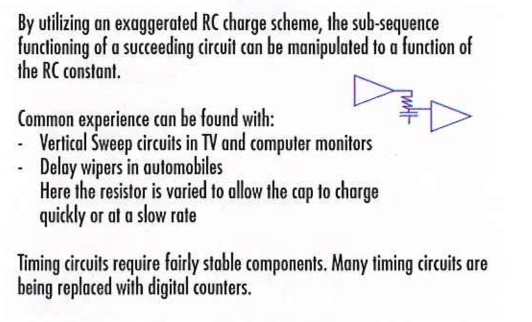


Figure 5 : Timing/wave-shaping

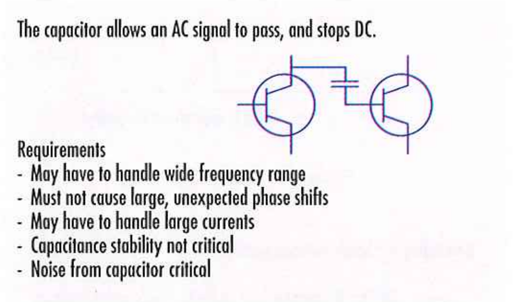


Figure 6 : Coupling

Coupling applications are extensively used in many circuit designs (Fig. 6). Here the inherent capability of a capacitor is used: it can pass AC, but blocks DC. In successive stages within an amplifier, the signal passes through the capacitor from one stage to the next, without upsetting the required static DC bias conditions of either stage. The requirements of these capacitors are that they offer little impedance to the desired AC signal, they do not distort the signal, and they can handle the AC current without significant internal heating. For small signal applications and with their surface mount capability, ceramic capacitors dominate this market, but they generate mechanical parasitics (piezo electric) to electrical signals. In lower frequency applications, they cannot be cost effective in offering large capacitance values available from the tantalum and aluminum.

The tantalum and aluminum are electrolytic and polar, whereas ceramic and film are not (they are bi-polar). This precludes the usage of the electrolytic types where the signal can swing to both polarities. In coupling, the static DC bias conditions usually allow that the AC signal is superimposed on a large DC difference, and the polarity of the coupling capacitor can be maintained, if necessary.

DECOUPLING

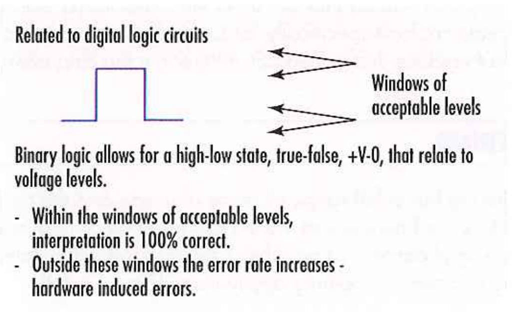


Figure 7 : Decoupling ideal

Decoupling has been the single most important reason that has led to the enormous growth of ceramic capacitors over the past thirty years (Fig. 7). It is the largest application market for the ceramic capacitor industry. These surface mounted capacitors, mounted adjacent to each IC in digital circuits, have tied the growth of the capacitor industry to that of the IC industry. It has most prevalently been defined as a ceramic dominated market, but it also involves the other types.

A digital circuit is based on a binary state determination of high or low, true or false, "1" or "0". These states have a desired voltage level used in their determination, and a window or range of voltage where the proper state can be read correctly, every time (Fig. 8). Signals or levels which start to fall out of these windows of absolute accuracy result in errors of determination, or errors in the computational activity of the circuit. They can bounce in and out of these windows because of RF noise on the bus, created by many other elements switching states at once. They can be delayed by resistance of the lines or that resistance inherent in the capacitor, causing a delay in the change of state (Fig. 9). They can appear to be proper at first then drop out of the window as many other elements are taking energy from the external circuit to change their states, and the energy depletion appears as a loss of voltage or "droop" (Fig. 10).

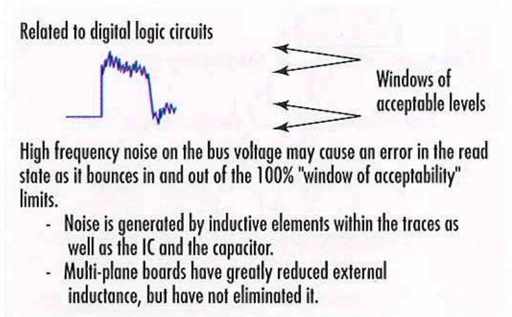


Figure 8 : Decoupling RF noise

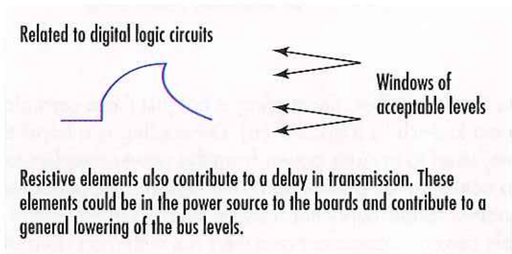


Figure 9 : Decoupling RC delay

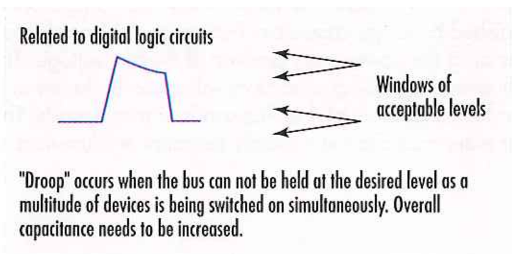


Figure 10 : Decoupling with 'droop'

These error conditions are caused by the inability of the power source to transfer energy quickly and quietly when requested to do so. The eventual transfer of energy is from the power supply (the energy source) to the IC, and the physical separation of the ICs from the power supply dictates that there be a time delay in transferring the energy because of the resistance and inductance associated with the circuit traces between the power supply and the IC. The circuit level decoupling capacitor is supposed to act as an energy supply that is physically located right next to each and every IC. This capacitor must transfer multiple bursts of energy to the IC without appreciably losing voltage as its energy is depleted. In order to accomplish this the capacitance value is chosen so that it can handle from 50 to 100 transfers of minute energy transfers without an appreciable voltage drop out of the window of absolute accuracy. In the time that 20 or 50 transfers have occurred, the power supply sees the minor drop in voltage and begins to replenish that capacitor's charge.

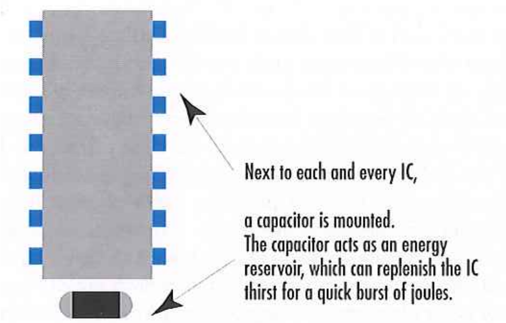


Figure 11 : Decoupling IC and capacitor

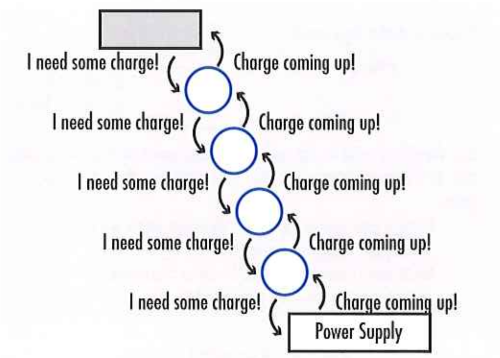


Figure 12 : No decoupling creates delay

As I stated earlier, decoupling is not just those ceramic capacitors next to each IC (Figs. 13-16). Decoupling is a hand-down scheme, used to transfer power from the power supplies to the ICs. In actual circuit applications, the ceramic capacitor feeds the IC. Another larger capacitor may be situated in the circuit to feed multiple ceramic capacitors and their ICs within an area of the board. These capacitors will be larger in value, from 10 to 50 times the ceramic capacitors' summary value. They could be ceramic, or they could be tantalum. Then these capacitors are replenished by larger capacitors located on the boards' perimeters or at the power entry position of the bus voltage. These power entry decoupling capacitors will again be larger in value, and in the range of 10µFd to thousands of microfarads. The power entry capacitors are usually tantalum or aluminum.

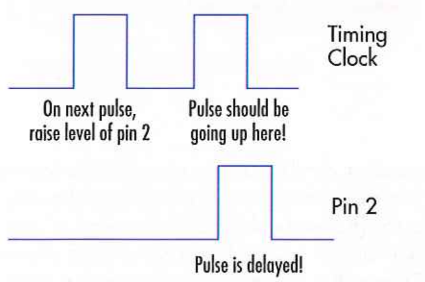


Figure 13 : No decoupling, timing delay

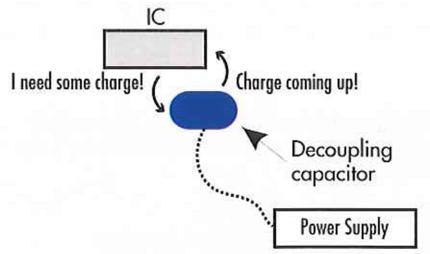


Figure 14 : Decoupling eliminates delay

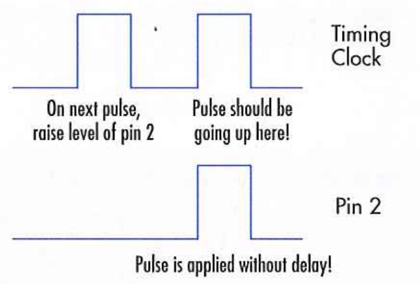


Figure 15 : Decoupling timing

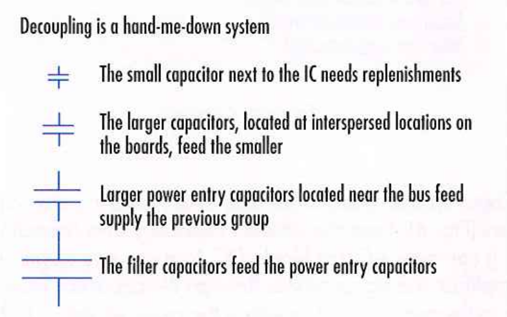


Figure 16 : Decoupling: the big picture

Lastly, the output filter capacitors of the power supply must hold the bus up during sudden power demands from multiple board energy demands. In all, the capacitors must allow a transfer of charge in a time element that does not generate a deficiency or create a noise pulse that would ring as RF on the bus. As the capacitors get closer to the IC, they must have lower inherent parasites of resistance (Effective Series Resistance or ESR) and inductance (Effective Series Inductance or ESL) - they must become "more perfect".

There is an additional step being added to decoupling schemes today that involve some of the faster and more complex microprocessors. There are land areas or pads built on top of the ceramic packaging to mount ceramic chips directly on the IC package. These pads are then short connected to the bus input areas of the IC die to eliminate the added length of connection through the traces internal to the IC package, through the pin to the circuit, then through the circuit to the capacitor(s). Some of these pads are built specifically for low inductance ceramic chip designs to reduce that added ESL inherent in the chip even further.

FILTERING

Filtering has a full range of areas of usage and the types of capacitors used here are as varied as the range of frequencies. Even the application can be subdivided into frequency selective filtering or power smoothing applications (Figs. 17-19).

In frequency selective filtering, a filter takes advantage of a capacitor's inherent ability to decrease impedance with increasing frequency. In a circuit where a capacitor is in parallel with a load, as the frequency increases, a greater percentage of the input signal is shunted through the capacitor to ground, instead of into the load. At low frequencies, the capacitor offers a high impedance, and the signal goes mostly to the load. This is known as a low pass filter design as the low frequencies pass on while the high frequencies do not. This is typical in most EMI/RFI filter applications. Remember that is also apparent in decoupling schemes. The capacitor is supposed to squelch the RF noise.

Parasitics in these capacitors will limit the useful frequency of operation. The capacitor will continue to lower impedance as frequency increases up to the point where its ESL becomes significant. The capacitor will go into a self -resonance and after this point, the impedance will increase with increasing fequency.

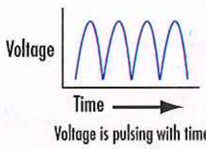
Filtering can have two distinctive functions that both remove unwanted signal or line variations:

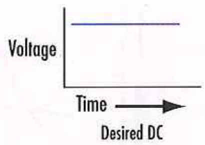
- Frequency Selective Filtering
  - A low pass, high pass, or band pass configuration
  - Most often used application is high frequency by-pass
- Rectified AC Smoothing
  - Eliminates the pulsing from low to peak by alternately absorbing energy during the peaks, and releasing it during the valleys.

Figure 17 : Filtering

As frequency increases, more of the signal chooses the alternative path, less goes to the load.
A variation of this circuit will allow only the higher frequencies to go to the load as the lower frequencies are channeled around it.

Figure 18 : Frequency selective filtering





Capacitor charges as voltage attempts to go high, and discharges as voltage attempts to go low.

- Capacitance value is high as it must stabilize this voltage and feed current to circuit during discharge
- ESR is of critical importance (heat - efficiency)
- Capacitance stabilization acceptable for ± 20% variations.
- High ripple currents!!

Figure 19 : Power rectification filtering

POWER SMOOTHING FILTERS

In a rectified power supply, a capacitor is used on the output to smooth the pulsing energy. The rectified AC is a pulsing DC with peaks and valleys. The capacitor is supposed to charge to the peak voltage levels, and maintain that voltage during the valleys.

The most prevalent power supply circuit designs today incorporate DC-DC converters. Though their name may imply that the circuit somehow amplifies DC input to the desired DC output level, there is actually a lot of AC conversion and power manipulation that occurs between the input and output. There are two main design schemes of DC-DC power supplies: the pulse-width modulated, and the resonant converters. The capacitor usage internal to these designs may incorporate a coupling capacitor, resonant capacitor (resonant converter), snubber capacitors (energy shock absorbers), signal conditioning for the control circuitry, and input and output filter capacitors. Regardless of which scheme is used and which variation, there will always be input and output filter capacitors.

As briefly described above, the output filter capacitor is meant to maintain the voltage near the peaks of the rectified AC, and hold it there during the valleys. The degree to which the capacitor can maintain that voltage is first of all defined by the capacitance of the filter, and the load resistance or current. This factor is the first used in calculating the desired capacitance and is known as the RC calculation. Whatever allowable change in DC voltage is determined by how much voltage the capacitor loses in the valleys between refreshing peaks, considering that the rate of charge loss is determined by the load current.

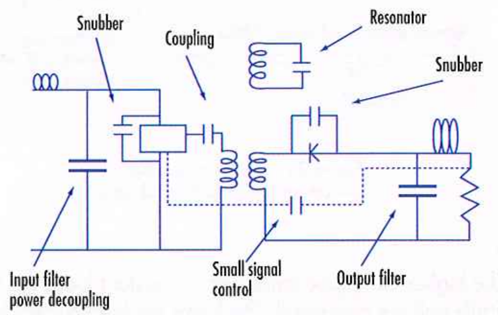


Figure 20 : Switch mode power supply capacitor usage

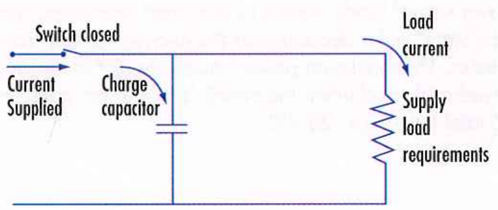


Figure 21 : Switch mode power supply: charge (on cycle)

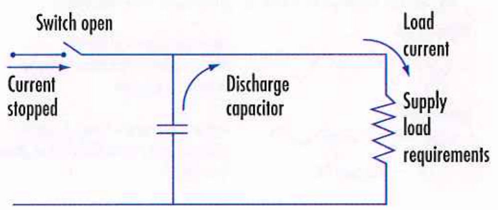


Figure 22 : Switch mode power supply: idle (off cycle)

Operation of a pulse-width modulated DC-DC converter is fairly easy to understand. A switch mechanism (FET) switches the input current to the output on a periodic basis (Figs. 20-24). When the switch is closed, the input current supplies current to the load and to the filter capacitor. When the switch is open, the capacitor must now supply current to the load. The frequency between on pulses is constant. The capacitor's voltage increases when the switch is closed, and decreases when the switch is open. This changing voltage is the primary element of the "ripple" voltage of the power supply. This ripple is extremely critical, especially for digital circuits with known "windows of absolute accuracy".

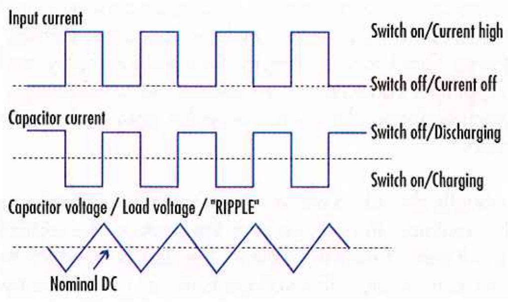


Figure 23 : SMPS timing diagram - full power

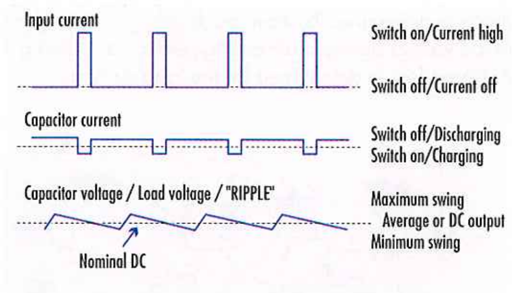


Figure 24 : SMPS timing diagram - low power (pulse width modulated)

The higher the capacitance with a constant load, the lower the ripple voltage generated. The lower the load current for a given capacitor, the lower the ripple voltage generated. For a supply with varied load, we cannot change the capacitance. The period of the switch "on state" is used to accomplish a stable voltage over varied loads. As the load current decreases, the width of the "on state" pulse decreases as the energy transfer from input decreases. The maximum power capability of this design is achieved and rated when the switch is in the "on state" for 50% of the total time (Figs. 25-29).

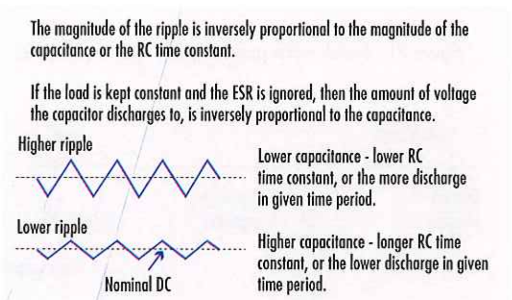


Figure 25 : CR ripple - capacitance effects

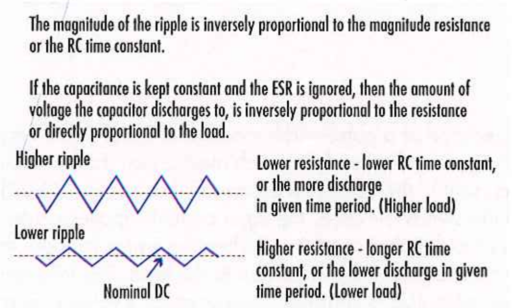


Figure 26 : CR ripple - resistive or load effects

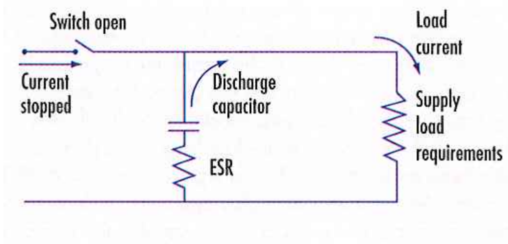


Figure 27 : ESR inhibits charge/discharge

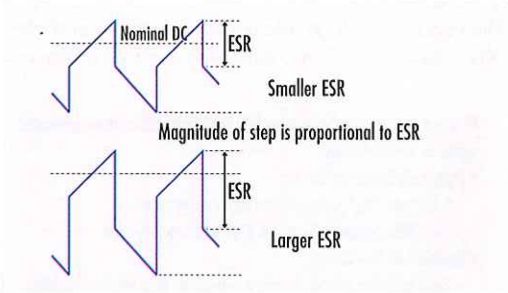


Figure 28 : ESR step effect in CR ripple

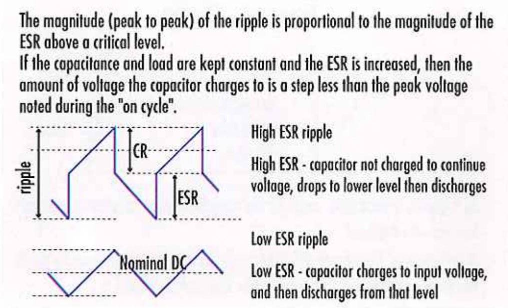


Figure 29 : CR and ESR ripple

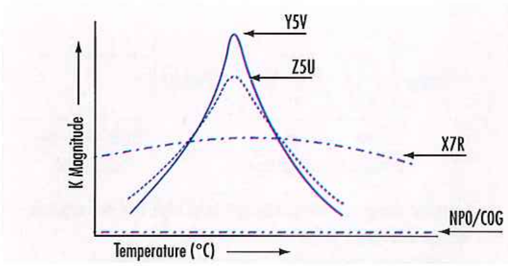


Figure 30 : Relative ceramic temperature effects

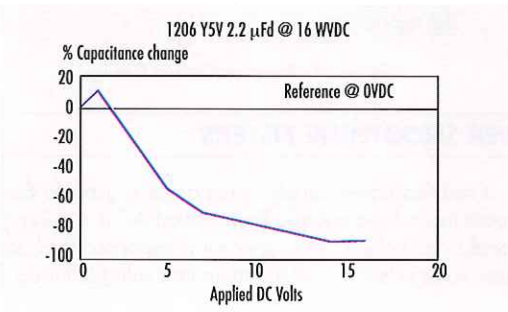


Figure 31 : Voltage coefficient of high K

What happens if the capacitor is not ideal, and contains ESR and ESL? The ESR is a very real problem in this application. During the "on state" the voltage developed across the load is divided across the capacitance and ESR of the capacitor. When the switch opens, the voltage available to the load is now immediately reduced to that lower voltage across the capacitor. In addition, the ESR now robs some of that voltage, causing an additional step decline in voltage. These ESR step voltages are now added to the CR ripple effect, causing a much higher ripple (Figs. 30-31).

The ESL element of the capacitor causes a voltage spike that is proportional to the magnitude of change in current divided by the change in time (Fig. 32). If the switch goes from one state to the other, the current in the capacitor changes from input (-i) to output (+i), within the given response time of the switch (dt). This change (2i/dt) multiplied by the ESL results momentarily in a voltage spike in the same polarity direction as the subsequent CR voltage slope. The frequency capability of the pulse-width DC-DC converter is restricted because of this characteristic.

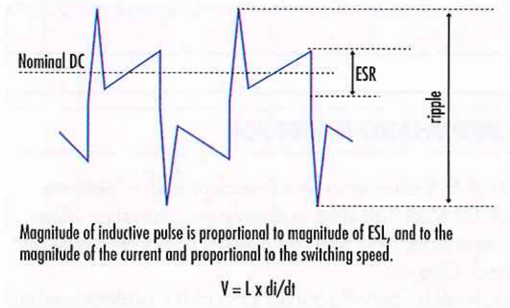


Figure 32 : ESL inductive spikes

An additional characteristic of the electrolytic capacitors can cause additional ripple voltage. As frequency increases, capacitance decays. For the aluminum, this decay can begin as early as 1 KHz, while with the tantalum it is not apparent until 50 to 200 KHz, depending on the value of capacitance. In a time domain, this relates to small capacitances at the short periods, with increasing capacitance as the time period lengthens. These capacitors act as if they were a two terminal RC-Ladder circuit. For the CR ripple, this causes an increasing slope (small capacitance) at the beginning of the slope, decaying to a constant slope (rated capacitance) at some longer time period. This higher slope at the beginning increases the overall CR slope deviation, and therefore, the ripple (Figs. 33-37).

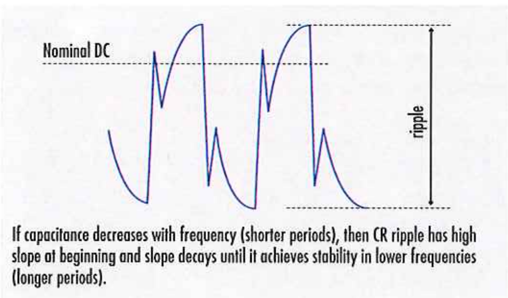


Figure 33 : Capacitance decay with frequency

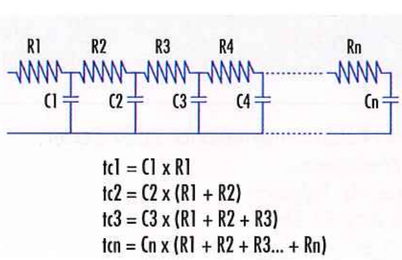


Figure 34 : RC ladder network

In the resonant converter, the output filter capacitor charges to the peak rectified voltage, and based on capacitance and load, discharges to an acceptable level during the valley or in between rectified pulses. In order to accomplish an allowable decay (ripple) over a varied load condition, the frequency of the oscillating circuit increases, allowing a shorter time between peaks, and even though the rate of decreasing voltage is increased, the total ripple is maintained to a lower level with the increased frequency.

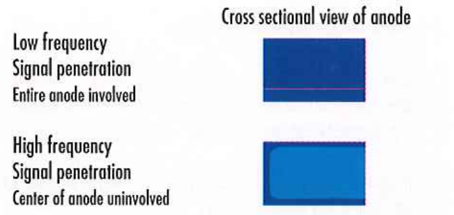


Figure 35 : Anode penetration vs. frequency

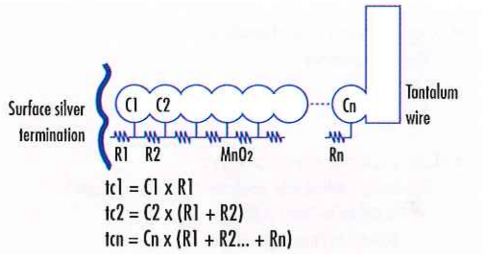


Figure 36 : Tantalum RC-ladder

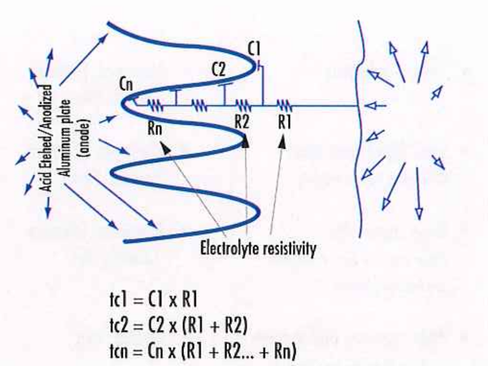


Figure 37 : RC-ladder in aluminum electrolytic

The input filter capacitor will generate similar voltage responses, and in many cases the parasitic additives will appear here also. The thing to remember for the input filter is that the allowable ripple here is much higher than the output, as long as it stays here. If the supply starts to radiate or conduct the RF energies out, then compliance with EMI/RFI standards fails.

Many new applications of ceramic and film capacitors in these power supply circuits are taking place by utilizing higher switching frequencies. The higher the frequency the lower the capacitance required, but higher frequencies put tighter restrictions on ESR and ESL. In lower frequencies, multiple capacitors could be used to achieve lower ESR in the output filters. In many cases, the capacitors used were not chosen for their capacitance capability but for their ESRs. With higher frequencies, the ESL of multiple capacitors can involve additional ESL in the connecting circuitry. The larger surface mount ceramics offer the most ideal capacitors for these applications.

The type of ceramic can be a debilitating factor. High capacitance with thin sheet Y5Vs have large variations of capacitance with temperature and DC bias. Care must be exercised when choosing one of these elements to maintain capacitance over the desired temperature range at the DC bias conditions of the bus.

- Higher voltage and lower capacitance
- Energy transfer is from capacitor through switch (FET) to load. Efficiency of energy storage of capacitor ($\frac{1}{2}CV^2$) is proportional to capacitance but square of voltage.
- Magnitude and speed of transfer are dependent on resistance (ESR) and delayed by inductance (ESL).

Figure 38 : Input filter - power decoupling

- Applications are changing
  - Higher Frequencies
  - Smaller
  - Surface Mount
- Components are changing
  - Previously "unthinkable" applications now being pushed
    - Tantalum in Power Supplies
    - Ceramic in Power Applications
  - Normal maturity of products has included many refinements

Figure 39 : 'Why change from what's worked?'

• Power Applications	• Aluminum, Tantalum, Ceramic, Film
• Small Signal Processing (Decoupling, Bypass, Coupling)	• Aluminum, Tantalum, Ceramic, Film
• Large Capacitance (Power Entry, low Current Hold-Up, low Frequency Bypass)	• Aluminum, Tantalum, Ceramic, Film
• High Frequency, High Current (Oscillator, High Frequency Bypass)	• Ceramic, Film

Figure 40 : Applications now have options

DIRECTIONS

Decoupling higher clock frequencies will push decoupling to an IC internal state. The capacitance required internally will be substantially lower than that required externally, but it should be remembered that decoupling is a hand-down technique, and the external capacitor will stay regardless of internal capacitance.

Decoupling will push the requirements for lower ESL in the ceramic chips. The ESR and ESR of the other types make them prohibitive in the circuit level or sub-circuit levels. For area decoupling or secondary decoupling, especially with advancing energy requirements of new microprocessors, the parasitic elements of the tantalum and aluminum will always be areas of concern and necessary development (Figs 38-40).

In filtering applications, there will be large inroads made by large value ceramic chip capacitors. The issue with ceramics is mechanical as large chips bring thermal and mechanical forces into play to affect robustness.

Polymer film electrolytes as well as solid state salt electrolytes are offering lower and lower ESR for the aluminum electrolytics. Several attempts have been made for surface mount capability, but none so far have proven widespread acceptance.

The tantalums must address lower ESR through materials and process innovations to maintain an advantage over aluminum. Low capacitance values are being taken over by ceramics, and now the surface mount and lower ESR advantage over aluminum is under attack.

DLA

Tantalum and Niobium Materials ex US Defense Logistics Agency

The US Defense Logistics Agency has received authorization to sell a number of materials from the Government's strategic stockpile in its materials plan for the 1997 fiscal year. Among a number of metals which USDLA has received permission to sell, are the following which are of interest to our industries: 60,000 lbs of niobium in ferro niobium, 20,000 lbs of tantalum in the form of tantalum oxide, 2,000 lbs of tantalum in the form of tantalum carbide and 100,000 of tantalum in the form of tantalum minerals. The fiscal year of the Government ends September 30th 1997.

DR. BERNHARD F. KIEFFER

Dr. B.F. Kieffer who was President of the Teledyne Advanced Materials died suddenly on December 26th 1996 at the age of 62. He suffered a heart attack on his way to Portland, Oregon.

Dr. Kieffer spent the major part of his professional career with Teledyne. He joined Teledyne in 1962 when he went to work for Wah Chang in Albany and later he transferred to Huntsville, Alabama where the Teledyne Advanced Materials have their headquarters. Dr. Kieffer was well known in the refractory metals and cemented carbide industries and will be missed by his many friends.

MEMBER COMPANY NEWS

Siemens Matsushita

Dr Schnabel retired in January 1997: we wish him a long and happy retirement. He is succeeded by Dr Josef Gerblinger as the delegate of Siemens Matsushita Components.

Lydenburg Exploration

Lydenburg Exploration Limited is under new management: the address has not changed, but there are new numbers for telephone and fax, and a new postal adress:

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