The Advent of a Stable Tantalum Supply Chain and Why It Matters to System Designers

Introduction

Tantalum capacitors with polymer cathode systems (sometimes called Polymer Electrolytic Capacitors) have outstanding characteristics that make them the preferred choice, from a technical point of view, for many applications. However, historical concerns over the sourcing of raw materials, and the stable supply and pricing of components, continue – sometimes, and in some companies – to overrule engineering judgement. This can force designers to choose a second-best solution instead of ensuring that the best available technology is designed into each project to deliver superior performing products to the market.

Technical advances, improvements in the tantalum supply chain, and discoveries of new and commercially reachable deposits of tantalum ore have taken away any justification for choosing a substitute technology in applications where tantalum would be the ideal solution.

The first section of this paper describes the technical advantages of tantalum polymer capacitors, and how and why they offer a superior solution to other capacitor technologies. The second section looks at the reasons behind some companies' reluctance to use tantalum capacitors and discusses how these fears have been eliminated by developments in the supply chain in recent years. Today's tantalum capacitors are better by design and safe for business.

1. Tantalum Capacitors: Technically the World's Most Wanted

Capacitors are vital for managing signals, noise, and power in a multitude of electronic devices ranging from high-end computer and consumer equipment to network infrastructure, industrial tools and aerospace applications. From the designer's point of view, the perfect capacitor often needs to provide tens, hundreds, or even thousands of microfarads (µF) of capacitance in miniaturized package sizes, and display no change in capacitance with applied voltage, temperature or time in the field. Moreover, it should introduce no noise to the circuit, and should also have extremely low parasitic resistance (ESR), high ripple-handling capability, and years to decades of life expectancy. Unique among the wide variety of capacitor technologies that offer excellent properties for diverse applications, tantalum capacitors offer close to ideal performance in each of these respects. Designers in some companies are free to take full advantage of the known strengths of tantalum technology to deliver superior solutions, while others are constrained and must choose the second-best device which delivers less than optimal performance and design.

The next sections examine the qualities tantalum capacitors have to offer from an engineering point of view.

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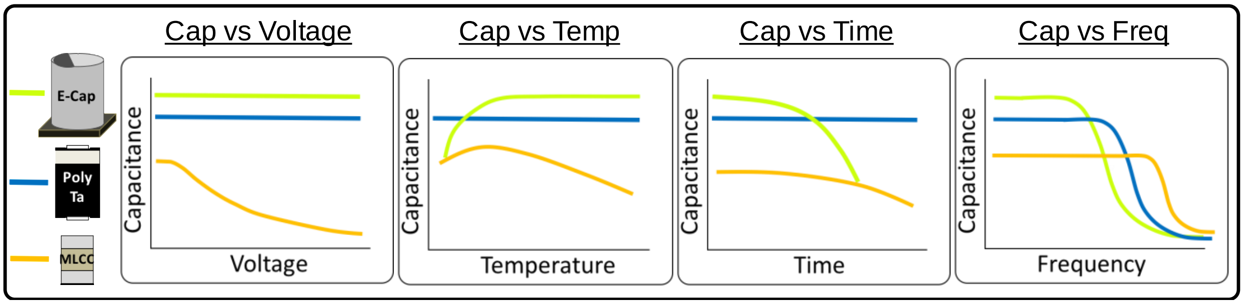
1.1. Electrical Properties of Tantalum Capacitors

Solid tantalum capacitors are available in two types: those with an MnO_2 cathode, sometimes referred to as “classic” or “traditional” tantalum capacitors, and those that feature the newer polymer cathode technology. Many designers and component engineers within the electronics industry do not define polymer cathode types as being a tantalum capacitor and often just refer to them by market trade names or simply call them polymer capacitors.

Both types have unbeatable volumetric efficiency, compared to other capacitor types. This characteristic alone has made them the preferred choice of designers seeking aggressive miniaturization while at the same time significantly increasing the functionality of new product designs. MnO_2 and polymer tantalum capacitors offer outstanding performance in many other respects:

1.1.1. Stable Capacitance

Compared to all other dielectric options, tantalum capacitors offer the most stable capacitance. Unlike MLCCs, the capacitance does not change when voltage is applied. When operating at high and low temperature extremes, tantalum capacitors experience no relevant change in capacitance. Over the lifetime use of the device (even a 20-year application) there is no notable change that occurs, unlike wet electrolytic capacitors that will dry out or MLCCs that experience an aging effect. Due to their higher ESR, MnO_2 tantalum capacitors will experience a drop in capacitance at switch frequencies exceeding 10kHz. However, polymer tantalum capacitors experience very little drop in capacitance at frequencies approaching 500 kHz to 1 MHz.



1.1.2. Temperature Range

Given their solid-state design, tantalum capacitors experience no issues at temperatures as low as -55°C and beyond. Polymer tantalum capacitors become limited as temperatures exceed 105°C. MnO_2 capacitors can operate well beyond this range and can be designed for applications of up to 200°C.

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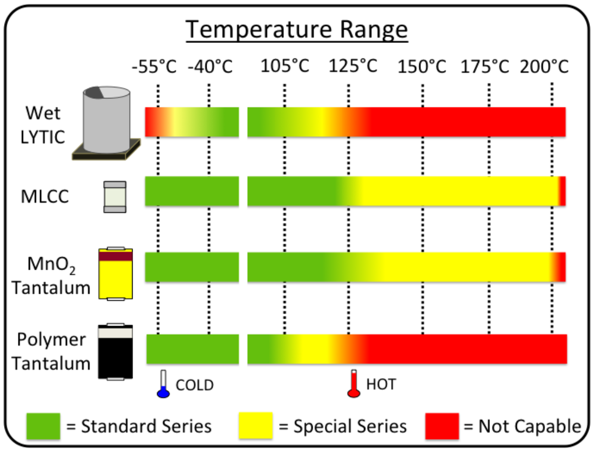


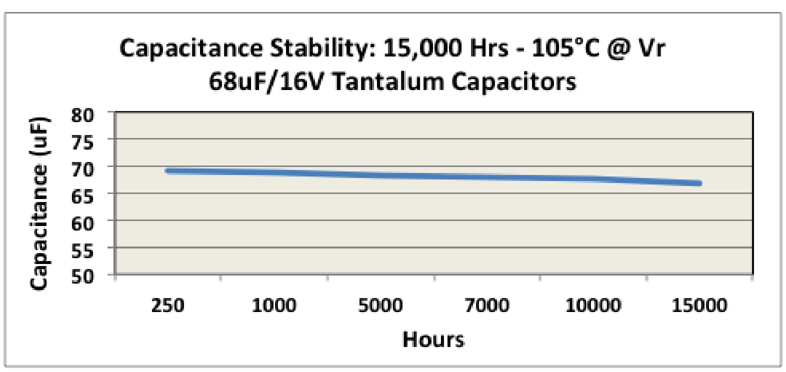
1.1.3. ESR

Historically, ESR was considered to be the greatest weakness of MnO_2 tantalum capacitors given the loss of capacitance observed as switching frequencies exceeded 10 kHz. This limitation was what prompted the introduction of polymer cathode systems.

Today's polymer tantalum capacitors have effectively extended capacitance roll-off to frequency ranges beyond 500 kHz. Polymer capacitor options with ESR values as low as 5 mOhms are available today compared to MnO_2 tantalum capacitors that can only reach 40 to 50 mOhms.

1.1.4. Reliability

Given the lack of a wear-out mechanism, tantalum capacitors are not considered to be a limiting factor in the lifetime expectancy of circuit designs. Accelerated life testing establishes the expected life of tantalum capacitors to be in the hundreds to thousands of years when used under common application conditions. This characteristic makes tantalum the go-to solution for hardware with life expectancies of more than a few years.



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1.2. MnO_2 Ignition Failure Mode

One point of genuine concern to some designers is associated with MnO_2 capacitors. Owing to the high levels of oxygen found in the cathode system, it is possible for the capacitor to ignite or produce smoke in the event of short-circuit failure allowing excessive current to pass. Today's polymer cathode systems have overcome this issue to deliver devices that offer a combination of low ESR, long life, stable application performance, high capacitance, low profile, small footprint and a safe failure mode. Polymer capacitors now represent nearly all of the new design activity in the industry, and are the capacitor of choice for products ranging from smart phones to smart homes and base stations to space stations. Their performance cannot be easily replaced with any other capacitor solution, which makes them a number one choice for many applications. Do note that the MnO_2 capacitors continue to offer superior characteristics such as lower leakage current for battery-dependent applications like hearing aids and higher maximum operating temperature ranges for applications like deep oil drilling and engine-compartment electronics.

1.3. Spotlight on Tantalum Polymer versus Aluminum Polymer Performance

Polymer aluminum capacitors are the closest rivals to polymer tantalum in several respects, and warrant special consideration as an alternative technology.

KEMET began developing polymer aluminum capacitors (H-Chip capacitors only) and polymer tantalum capacitors at about the same time and has extensive design and manufacturing experience with each.

1.3.1. ESR

Given the multiple layers of aluminum elements placed in parallel in the package, aluminum was the clear winner for applications in which every milliohm of ESR is critical. Whereas polymer tantalum can reach values as low as 5 mOhms, polymer aluminum can achieve values of as low as 2 mOhms with no added complexity in design. The reduction in ESR has the added advantage of slightly higher capacitance retention as switching frequencies approach 1 MHz.

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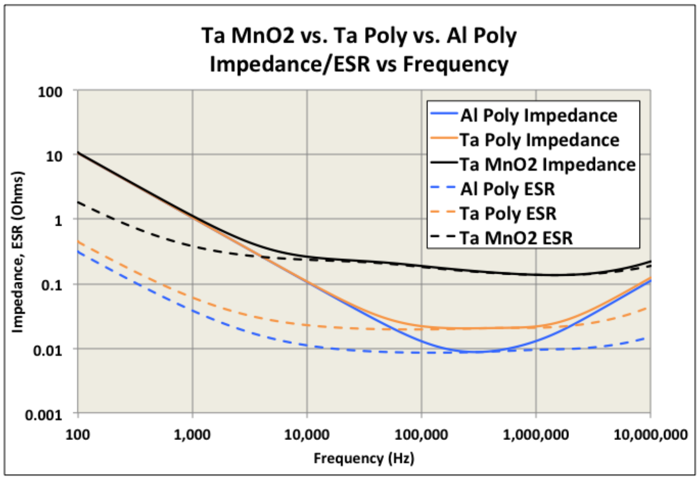
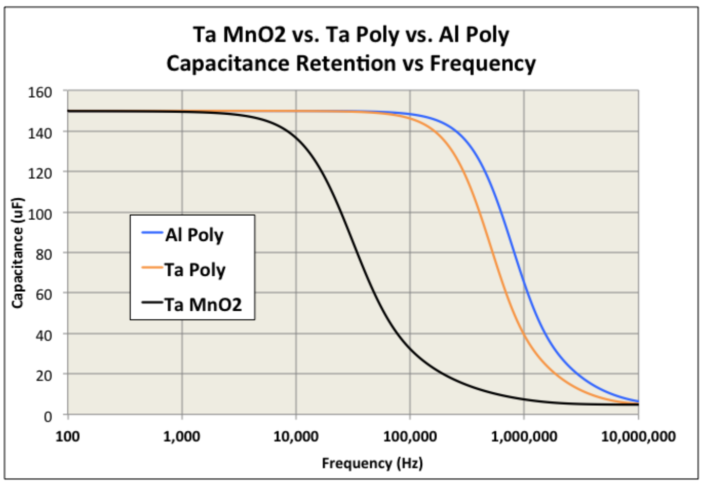


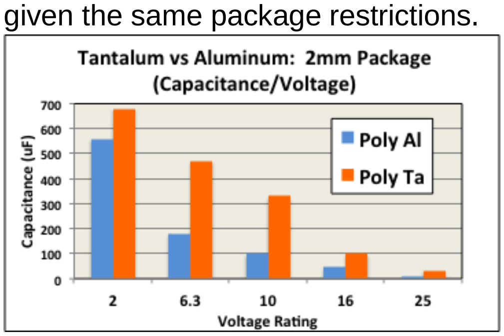
Impedance & ESR Comparison: 150µF/6.3V Capacitor



Capacitance vs Frequency: 150uF/6.3V Capacitor

1.3.2. Energy Density

Polymer tantalum will always be the winner for maximum volumetric efficiency. At best, aluminum can achieve 50% to 80% of the maximum capacitance achievable with tantalum, given the same package restrictions.



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1.3.3. Voltage

To date, development efforts have been unable to deliver a low-profile polymer aluminum design with voltages greater than 35 V. In comparison, polymer tantalum options are available in values of up to 125 V.

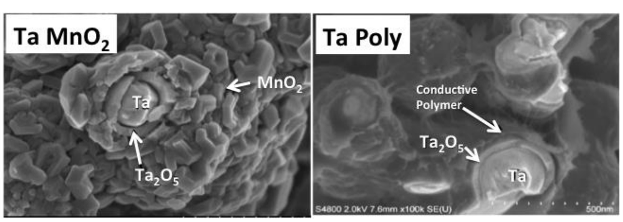
1.3.4. Case Size

Given the internal construction of polymer aluminum capacitors, significant space within the package is allocated to areas other than active capacitance. As package sizes are reduced, it is the active capacitance area that must be reduced in a polymer aluminum capacitor to address the smaller package size. As packages downsize from the standard 7343 size (D Footprint), capacitance rapidly drops for aluminum capacitors thus leaving polymer tantalum capacitors as the clear winner in smaller case sizes. Today, low-profile aluminum polymer capacitors are still limited to the 7343 case size while polymer tantalum capacitors are available in a wide range of footprints.

Given the unique advantages of each construction type, KEMET continues to invest in both technologies. A new generation of both aluminum and tantalum capacitors are currently under development that will extend the energy density offered by each dielectric type.

1.4. Continued Advancements in Tantalum Capacitor Performance

Unlike many capacitor technologies, tantalum continues to experience notable advancements in technology. Research in this area not only includes further refinements in the tantalum powder itself, but also improvements in the cathode systems that contribute to enhanced electrical characteristics such as ESR as well as packaging improvements that further extend the capabilities of operating in high-humidity or high-temperature environments.



3-D Structure: Ta(Anode), Ta_2O_5(Dielectric), Cathode(MnO_2 or Polymer)

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Some of the major development trends are described below:

- Polymer tantalum capacitors continue to be the fastest growing area for this dielectric. Some of the most recent developments have delivered ESR values of as low as 6 mOhms in a B Case (3.2mm x 2.8mm x 2.0mm), 270 µF, 2.5 V design. High capacitance values of as much as 1500 µF are now available in a 7.2 mm x 6.0 mm x 2.0 mm package with a 6.3 V rating. Advancements in polymer technology have resulted in the release of higher capacitance parts in voltage ranges that exceed the reaches of traditional MnO_2 tantalum capacitors with new offerings available in 63 V and 75 V ratings for 48 V input applications.

- Automotive-grade polymer capacitors are at the forefront of development. While polymer capacitors have been available for more than fifteen years, a fully qualified AEC-Q200 product has not been available to the industry. Recent advancements in packaging have resulted in polymer designs that can meet all of the requirements of the Q200 document and still deliver the ultra-low ESR performance that has been of great interest to the automotive industry in recent years.

- High-temperature applications continue to demand more from tantalum capacitors. While becoming less common in the industry, MnO_2 cathode systems are needed to meet these temperature requirements. During the past 10 years, product offerings have moved from 125°C to 150°C to 175°C ratings. Today, 200°C products are now available with continued development efforts underway to achieve even higher temperature ratings.

2. No Longer a Risky Option

The technical advantages of tantalum capacitors promise opportunities for designers to deliver superior products to their target markets. Some designers, however, are restricted in their use of tantalum devices and must select the next best option. By definition, the chosen device will deliver inferior performance either from an electrical, physical or total cost perspective.

There are several reasons for the restrictions that force some designers to choose the second-best solution for their projects. These are mostly concerned with ethics and supply or pricing risks. However, these reasons are now outdated and no longer applicable.

2.1. The Ethics of Tantalum Production

Historically, much of the world's most easily extractable known tantalum ore has been located in the Democratic Republic of Congo (DRC). Unfortunately, this area has been in the grip of armed conflict for many years, and militias have sought to take advantage of the country's mineral wealth to fund their activities. These have included diamonds and minerals – namely tin, tungsten, tantalum and gold – extracted by mining communities placed under duress and subjected to horrific human rights abuses.

In the West, initiatives to prevent the trade in conflict diamonds and conflict minerals have sought to cut off funding to the militias in the hope of preventing further atrocities. Section 1502 of the Dodd-Frank Wall Street Reform and Consumer Protection Act and related US Securities and Exchange Commission (SEC) Final Rule issued in 2012, require companies to determine

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the origins of any tin, tungsten, tantalum or gold in their products and if sourcing from the DRC or adjoining countries to conduct due diligence on the source and origin of those minerals.

Some commercial organizations believe that avoidance of any trade with the DRC, or avoidance of any of the listed minerals altogether where possible, is the safest approach to ensuring compliance with the wishes of the Dodd-Frank act (and similar legislative or non-government pressure in other parts of the world). Unfortunately, this approach harms the prosperity of legitimate miners in the DRC.

KEMET has taken a different approach to the challenge of supporting international initiatives to stop the illegal trade in conflict minerals while also promoting legitimate trade with the DRC, which benefits the local communities and the tantalum supply chain in general. The key to KEMET's activities has been a partnership with a certified conflict-free mine in the DRC's Kisengo province. KEMET is working with local partners such as the Kisengo Foundation and international auditors[1] to ensure the mine is operated in accordance with respected codes such as the International Tin Research Institute Tin Supply Chain Initiative (iTSCi) Traceability and Due-Diligence System. The mine is managed fairly and safely by the Coopérative des Artisanaux Miniers du Congo (CDMC). KEMET is also contributing funding to local infrastructure projects, in addition to ensuring that the revenues from the mine are fairly distributed to the miners and invested in the local community.

In June 2014, KEMET was the only capacitor manufacturer to file an independently audited Conflict Minerals Report with the U.S. Security and Exchange Commission (SEC) declaring its surface-mount tantalum MnO_2 and polymer tantalum capacitors to be "DRC Conflict-Free". Some 1300 additional companies also filed reports with the SEC in 2014. In total, only four of the 1300 companies met these requirements. Three of the four companies are known as leaders in the electronics industry. For the 2015 reporting year KEMET declared all tantalum products to be "DRC Conflict-Free". (To learn more about KEMET and the DRC, please visit www.kemet.com)

KEMET's radical approach to the sourcing of raw tantalum ore fundamentally answers the ethical issues surrounding the use of tantalum in capacitor production. Importantly, it also secures the first stage in KEMET's revolutionary closed-pipe, vertically integrated supply chain that effectively eliminates price instability and lead-time fluctuations – uncertainties that in the past have convinced some hardware companies to avoid tantalum capacitors altogether.

2.2. Perceived Supply Risks

KEMET's closed-pipe, vertically integrated supply chain gives complete control over all aspects of producing capacitor-grade tantalum powders and other necessary products such as tantalum wire. This effectively stabilizes both price and availability.

Historically, it is true that pricing and lead-times for tantalum products have experienced periods of instability. Two key factors lie at the heart of this problem: during the technology boom of the

[1] The site has been audited by the International Tin Research Institute (ITRI), the German Federal Institute for Geosciences and Natural Resources (BGR), and the social development consultancy Channel Research.

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early 2000s, the known deposits of conflict-free tantalum ore were scarce, and supply was unable to keep up with rapidly escalating demands, leading to shortages, price fluctuations, and products being supplied on an allocation basis only. Moreover, those tantalum-ore deposits were mostly concentrated in hard rock, in a region of Australia, which made extraction difficult and expensive. In 2000, this was the only mining location supporting the capacitor industry. If the market price of tantalum fell below a certain level, mining would become commercially unviable, and activity would need to stop until the price had risen above the minimum threshold. This situation compounded the uncertainties surrounding pricing and supply.

Fortunately, since that time, further deposits have become available in areas such as the DRC. These deposits are contained in both hard rock and alluvium areas and can be extracted at a lower operating cost. Beyond the DRC, KEMET now sources it's ore from a multitude of other countries in this region as well thus adding further sourcing options and competition in the supply chain. The major cause of supply uncertainties and price instability has, therefore, been eliminated.

KEMET's vertically integrated supply chain means that ore can now be purchased directly from the source mine. Prior to these events, minerals traders and brokers often acquired stockpiles of tantalum ore in an attempt to influence the price. Traders would work to create artificial shortages in the supply chain thus increasing the ore prices and total cost of the finished capacitor. By purchasing ore directly from the mines, KEMET has removed this non-value-added step of the process.

KEMET has gone further by acquiring smelting, powder production and sintering enterprises based in the US and Mexico. Together with the mine in Kisengo province and other areas, these activities complete the vertically integrated closed-pipe supply chain. KEMET is thus able to rely not only on stable supply and pricing, unaffected by the interests of any external agents, but can also guarantee the provenance of all raw materials and the quality of all manufactured products. Moreover, KEMET is able to quickly prototype new materials and optimize the properties of any powders and metals to further improve tantalum capacitor performance.

2.3. Continuous Improvement in the Supply Chain

KEMET has not declared this to be the end of its efforts for supply chain stabilization and continues to work toward further assurance of supply. Today, KEMET is partnering with mines in other regions of the world such as South America, which contains even greater sources of recently discovered tantalum. Before these deposits were discovered, Africa was believed to hold up to 80% of the world's known tantalum deposits. Now, that estimate has been revised to just 10% of known deposits while South America has been declared as holding over 40% of the world's know supply. Additional new discoveries on other continents also account for the reduction in total estimated tantalum deposits in Africa.

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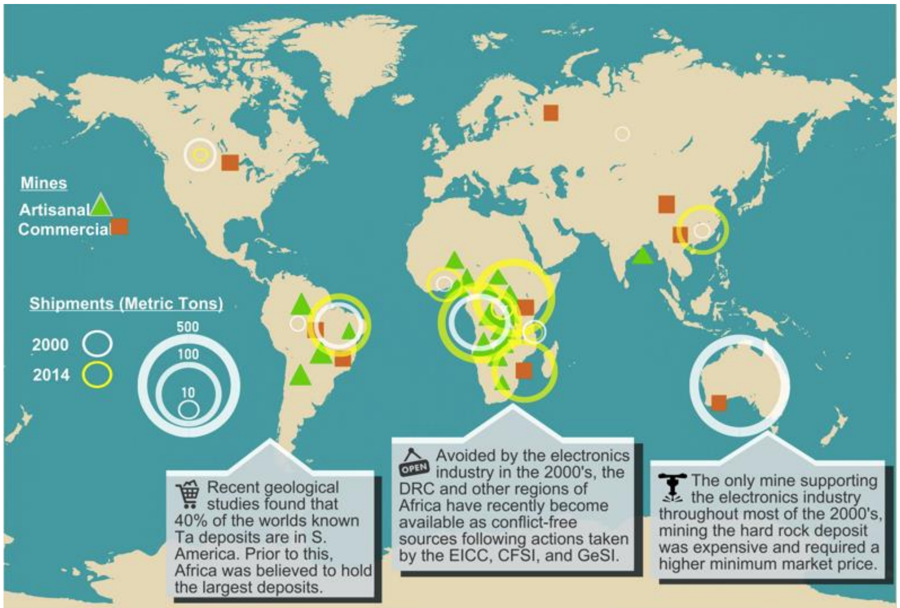

KEMET's first five years of supply-chain integration have brought about major changes in the sourcing of tantalum for capacitor production.

These improvements include:

- Reductions in raw material throughput time
- Stabilizing of ore pricing
- Removal of ore traders who work to artificially influence market prices
- 100% cost structure control from ore to powder
- Expanding KEMET direct ore suppliers from one supplier to many
- Holding its own reserves of tantalum ore

2.4. The Great World Tantalum Shortage Myth

As the situation stands currently, all historically valid causes for concern over supply, price or ethical issues surrounding tantalum have been overcome. Some companies established rules for designers in the 2000s that called for zero allowance of tantalum capacitors. Any such rules still in force today are based on outdated information, and these practices are preventing engineers from developing the best possible products for their target markets. One issue remains to be addressed: misinformation; most notably, the myth that the world will soon experience shortages of tantalum again.

In fact, current estimates of the amount of reachable tantalum, based on historic peak demand patterns, indicate that there is more than sufficient supply for the foreseeable future and possibly for the next 500 years (USGS Fact Sheet 2014-3054) based on currently known deposits including those recently discovered in South America.

It is worth noting that only half of the world's annual extracted tantalum ore is used to make capacitors. The remaining half is used in the production of many other products such as alloys for aircraft frames and ships, coatings for hard disk drives, electronic resistors, artificial joints,

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corrosion-resistant coatings for chemical manufacturing, additives for optics like camera lenses and displays, ultra-hard alloys for milling of metals, and heat-resistant metals for applications like jet and rocket nozzles. Since these industries or markets are not declaring concerns with their supply chain, it is apparent that the world has an adequate supply of tantalum. Anyone who is suggesting a potential shortage in the foreseeable future is likely just playing on customer fears and concerns.

Conclusion

Historically, many issues have complicated the supply of tantalum, and the design-in of tantalum capacitors. Today, however, the supply-chain risks, ethical doubts and even the few technical drawbacks of tantalum capacitors have been overcome. Designers are now free to choose the best solution to their design challenges based on engineering judgment. It is no longer necessary to choose the second best capacitor technology for any application where a tantalum capacitor is clearly the optimum solution.

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