The Next Generation of Passive Component Standards for New Space Electronics

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Abstract

The high reliability markets (space, aerospace, military, etc) are changing as commercial entities are successfully venturing into space and paving the way for the future. Within this white paper I aim to explore what this means specifically for resistive component technology and component standards. This white paper also explores the suitability against radiation effects in thin film resistor technology which becomes an important factor when operating in space environments i.e. NiCr networks vs. TaN Film networks against total ionising dose radiation (TID).

Introduction

What is "New Space" and what exactly am I going to be exploring within this white paper? Well the term "New Space" ironically isn't actually that new. The term has been in existence and used from the early 1980's and came about to describe companies that were starting to develop space systems capable of reaching outer space, without assistance from government space agencies such as NASA. This activity and independent development gave rise to a significant shift in US policy favouring private space activity. This resulted in the landmark Commercial Space Launch Act of 1984. The idea being that NASA and other large government based space agencies are bureaucratic and slow. By empowering private space activity technology moves faster, more competition is introduced further improving the technology. Examples of private space companies which have seen great successes within the last few years include SpaceX, Blue Origin and the Space Frontier Foundation.

Background

So now we know the term "New Space" has actually been around for a while why is it now gaining momentum again and being used more frequently. Quite simply it is because of the success of the aforementioned private space companies. As private companies have emerged and have been making significant breakthroughs for the private sector it has highlighted a gap in the market. The tables have turned and now NASA themselves buy privatised space technologies and launches. So what does this all mean? Well it is an extraordinary time to witness seeing a more rapid development and exploitation of newer technologies in space. Subsequently with the advent of newer technologies being adopted more readily under a New Space ideology it raises questions as to what component standards should be used.

Traditional Space

Aerospace and space electronics, before more commercialised technologies such as mobile phones, laptops, etc, were developed, consumed a large proportion of the semiconductor fabrication manufacturing. Therefore, at this time aerospace and space electronics dominated the development of semiconductor manufacturing. In the present where so much of the semiconductor fabrication manufacturing is dominated by commercial and automotive electronics the aerospace and space electronics market has little influence over the new semiconductor devices developed and qualification standards used. Therefore newer more sophisticated devices offering advantages over older devices are mostly qualified for commercial and/or automotive use only. Of course technologies are improving all the time. The more times you repeat a process using the same processing techniques you would expect the accuracy to improve over time from a series of incremental learnings and optimisations.

This consequently led to the aerospace and space electronics market turning to older commercial devices and up screening them to ensure reliability. This consequently meant that aerospace and space electronics would constantly lag behind commercial technologies. Traditional Space i.e. government space agencies i.e. NASA accepted this as their number one priority lies in ensuring safety and reliability. I.e. for manned missions or for large (up to the size of a double decker bus) geostationary satellites reliability is paramount. This has to be the case to ensure safety for humans on manned missions and to protect the significant value of larger satellites designed for mission cycles of 15 years+.

New Space Opportunities

Fig 1: https://www.ttelectronics.com/markets/aerospace-electronics/new-space-electronics/

New Space electronics challenges the premise of large long life geostationary satellites with smaller shorter life LEO (Low Earth Orbit) satellites and so questions the Traditional Space component qualifications. With commercial spacecraft lowering the cost of access to space and in particular LEO orbits there very well might be a paradigm shift to how we operate electronics in space. LEO orbits are also below the Van Allen radiation belts and so are not subject to high radiation doses which exist in the more distant Geosynchronous Orbits (GEO). This means that electronics in Low Earth Orbit (LEO) will not have to be radiation tolerant or radiation hard to the same degree as electronics in Geosynchronous Orbit (GEO). This has clear benefits leading to saving space and saving weight within the satellite structure.

New Space, being linked directly to private industries as defined right at the start of this white paper, also has more of a cost focus. Although space technologies are enormously expensive to develop private companies, however cash rich, will have less money to develop technologies in comparison to government organisations such as NASA. This subsequently leads private space development companies to operate in a more lean/efficient manner and keep hardware/component costs down. It has also seen companies such as SpaceX pioneer reusability strategies and technologies which are extremely impressive.

With these combining and coupling effects which New Space presents i.e. smaller, lighter, LEO orbit, reduced costs to launch and shorter lifecycles, all of a sudden the commercial space market starts to open up to companies who could have never before entertained the idea of operating their own payload in space. I personally believe that we are only just at the very forefront of space development in terms of the possibilities to create more sophisticated space hardware and infrastructure both inside and outside of orbit around the Earth. With quite a new and interesting market opening up the question becomes what does the electronics look like to support it?

Fundamentally the electronics themselves won't change, however it is clear that the new ideas supported by New Space support more commercially available COTS parts in comparison to heavily qualified traditional radiation hard older devices. I don't personally believe it is a choice of one or the other moving forward and that they will both run in tandem where required. However, it is apparent that if LEO satellite constellations take market share from GEO satellites then we may see a significant rise in more commercial electronics used in space.

Military & Aerospace Markets

Moving away from space for a moment and addressing military / aerospace technologies it is apparent that military and aerospace manufacturers implement component strategies dependent on the project. This supports the idea for both heavily qualified traditional and more commercial components to be used together. After all if a project is life critical reliability must be of the highest priority. This provides evidence that high space level qualification can run in parallel with lower grade component technologies. A primary example of this was highlighted by John Keller in an article he wrote and published on the 1st of June 2019 "Electronics in space: traditional market faces-off against New Space". The link to his article can be found here:

https://www.militaryaerospace.com/home/article/14035614/electronics-in-space-traditional-market-facesoff-against-new-space.

In this article John Keller talks about Curtiss-Wright Defense Solutions who have implemented modified COTS for space applications. This also supports my thoughts regarding how both heavily qualified traditional and more commercial components can to be used together. John explains Curtiss-Wright Defense Solutions have created an approach where space applications can be implemented economically and with the latest modern technology. From a pure Traditional Space perspective this would seem impossible but has been established due to the fact the both Traditional Space and New Space complement each other.

John Keller explains that customers of Curtiss-Wright Defense Solutions are worried about single-event upsets, which they are quite right to do so, however he goes on to say that Curtiss-Wright implement a radiation hard backplane that goes on the back of stacks of data acquisition modules. Therefore, in this case the system has radiation hard components built into the backplane, however the modules are COTS. If you encounter a single event upset the current usually spikes, however the radiation hard backplane is continually monitoring for such spikes. This gives the ability for the radiation hard electronics to protect and look after the COTS modules. The customer can program current limits in the event of an upset and then have the backplane reset the power to the upset module to clear the latch-up. Rather impressively the COTS modules can survive as many as 120 latch-ups with no degradation.

New Space Component Grades

It is apparent that due to the nature of New Space the advised component standards are far from defined. Everything from completely commercial electronics through to space qualified radiation hard parts has been used in space. The reality is that it depends solely on the primary purpose of the payload. I.e. if it is a CubeSat LEO project with no criticality or expectation of years of life then using fully space qualified radiation hard electronics would make no sense whatsoever.

This presents a new opportunity for both space system designers and space component manufacturers in defining new standards which are robust and reliable for New Space LEO orbits without being overly expensive. This might mean coming up with a new standard all together or adopting something like AEC-Q200 or an AEC-Q200+? It is only speculated currently about what would be an appropriate standard and as mentioned in every case it always relates back to what the intention of the mission is.

At TT Electronics we are starting to see Aerospace and Space look to using AEC-Q200 components so this may be a sign that things are starting to change already. With the New Space market predicted to grow in the coming years this is something that may increase the demand for automotive grade components.

Of course automotive grade electronics is already a growth market with much more electronics being designed into cars these days than ever before. This is also set to continue with more advanced vehicle platforms including fully electric and autonomous vehicles. These two factors also support AEC-Q200 becoming a standard which takes precedence.

So what will this mean for Traditional Space component manufacturers? As mentioned earlier within this white paper I don’t believe that one day we will not require fully space qualified components. New Space is disruptive technology and therefore will create a shift as the reliability of more cost effective component grades is explored. However, as more demanding and life critical applications grow in space reliability is always of paramount importance and should be fit for purpose in line with the primary mission objective, whatever that may be.

It is these new and existing applications which will drive the demand for fully space qualified components whilst commercial LEO satellite constellations will use cheaper component grades. It is for this reason for why I don’t believe it is a case of New Space versus Traditional Space.

What Does This Mean For Resistors?

Potentially for resistor components this will mean that not only MIL qualified or equivalent parts can be considered for various projects in Aerospace and Space. For example, other standards of component such as automotive AEC-Q200 may be possible to design with for some Aerospace and Space projects.

At TT Electronics, after recognising that AEC-Q200 is becoming a converging standard, we always try to ensure that new resistor products are launched with AEC-Q200 qualification where possible.

Radiation Effects in Film Resistors

Radiation effects within electronics are an extremely important topic when operating in space and even more so in more distant orbits such as Geostationary orbits.

In some components such as semi-conductors different device structures and new materials such as SiC (Silicon Carbide) the radiation effects are to this day still being explored and understood.

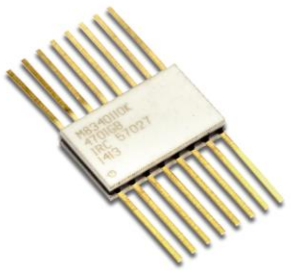


Fig 2: TT Electronics Tantalum Nitride thin film network
https://www.ttelectronics.com/products/categories/resistors/resistors/m83401xxxxa(fp)/

In this section we shall explore radiation in relation to New Space and in particular passive resistor components. Within this white paper we have already explored the idea of Traditional Space qualified radiation hard components working alongside COTS parts. However, if New Space sets precedence to using more COTS or automotive grade components then radiation data will not be available. This makes one ask the question of how radiation tolerant standard COTS parts are. For resistors the construction is mostly large feature bulk materials. Therefore, there is inherently less risk of permanent damage due to exposure to TID (Total Ionising Dose) or SEE (Single Event Effect) radiation types.

The primary concern arises upon small feature, thin layer and large 2D area devices. As you can imagine more complex devices such as transistors definitely fall into this category. Thus, for resistors, if we apply the above criteria, our concern becomes focused on mostly thin film resistor networks. Such networks are available in either NiCr or TaN film technologies. Nickel Chromium (NiCr) or Tantalum Nitride (TaN) film. To understand the radiation effects in one of our TaN thin film resistor networks we commissioned some radiation testing. This comprised of resistance measurements taken before and after neutron radiation, $10^{13}/cm^2$, fast neutrons and gamma radiation, 100kRads from a Cobalt-60 source. Five networks were tested with varying resistance values of 50Ω, 25kΩ and 50kΩ.

Results

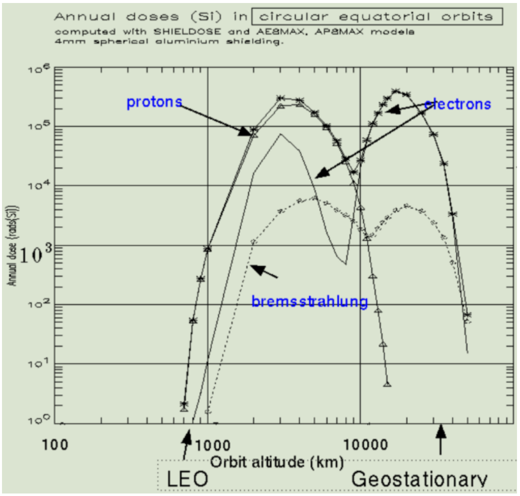
The results are presented below and assess the resistance variation before and after the defined radiation exposure. It is instantly recognisable that larger resistance variations are recorded for the 50Ω results. These resistance changes are believed to be caused by contact variations during the measurement.

Network Resistance		Network #1 % DELTA R/R	Network #2 % DELTA R/R
50Ω	Avg.	-0.008	0.011
	Sigma	0.027	0.045
	Max.	0.050	0.127
	Min.	-0.052	-0.036
25kΩ	Avg.	0.006	0.005
	Sigma	0.007	0.002
	Max.	0.028	0.008
	Min.	0.000	0.004
50kΩ	Avg.	0.003	-
	Sigma	0.002	-
	Max.	0.006	-
	Min.	0.002	-

Table 1: TT Electronics Radiation Results

Conclusions

Overall, these quantities of radiation have very little effect on TaN thin film resistor networks. When making a comparison to more wide spread test methods such as load life, dry heat and temperature cycling tests on the TT Electronics TaN WIN chip series you can see that they are an order of magnitude lower. They are also the typical radiation levels which you would find in LEO orbit i.e. 100kRads TID / year, see below Graph 1.



Graph 1: http://holbert.faculty.asu.edu/eee560/tiondose.html

In summary we can infer from this that COTS or AEC-Q200 grade TaN (Tantalum Nitride) thin film resistor networks could be used in LEO New Space applications with a good degree of robustness.

However, TaN (Tantalum Nitride) thin film resistors aren't as common in commercial marketplaces as opposed to NiCr (Nickel Chromium) thin film resistors which are well established, easier and cheaper to produce.

From research I have discovered a test which made a direct comparison between NiCr (Nickel Chromium) and TaN (Tantalum Nitride), albeit at higher radiation doses than we have tested for. The total dose irradiated to both film types was 10^{16} fast neutrons cm^{-2} and over 10^{8} Rads of gamma radiation. The Nichrome resistors, regardless of details of manufacture, all showed a fall in resistance, the median value being 0.035%.

However, after a similar irradiation the tantalum resistors, on the other hand, showed an increase of under 0.02%. The temperature coefficient of resistance (T.C.R.) of TaN resistors remained constant during irradiation, whereas that of the NiCr resistors showed a considerable increase.

These differences in behaviour are consistent with the assumption that the TaN films are continuous or have closely spaced grains and NiCr films are agglomerated. The model proposed by Robert Hill for conduction in agglomerated gold films offers an attractive explanation for the changes observed in NiCr resistors.

For more information see the source of this testing:

https://www.sciencedirect.com/science/article/abs/pii/0040609068900692

TT Electronics New Space Component Technologies

As markets continue to evolve with time and disruptive change it is important for component manufactures to keep up with the latest demands in the market. Quite clearly there is and will be more changes to come in the space industry.

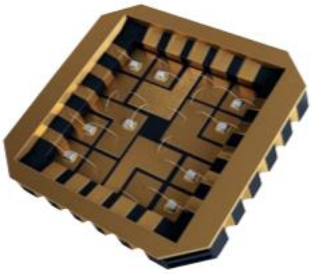


Fig 3: *https://www.ttelectronics.com/TTElectronics/media/ProductFiles/Semiconductors/Brochures/New-Space-Electronics.pdf*

Therefore, what is TT Electronics doing to support this market shift one might ask? Well, firstly we recognise from looking at several markets that AEC-Q200 is becoming somewhat of a converging standard. Therefore at TT Electronics we always, where possible, release new resistor products with AEC-Q200 qualification. TT Electronics recommends its AEC-Q200 resistor portfolio to be used in New Space applications along with our New Space MCA's and discrete portfolios which were launched during 2018.

TT Electronics is also working on certifying its range of TaN film chips resistors, WIN series, to AEC-Q200 qualification level. With radiation tolerant TaN film in combination with AEC-Q200 qualification and being reengineered to be more cost efficient, TT Electronics WIN series really is perfect for New Space applications.

New Space Unknowns

Although the New Space approach has many advantages in being able to utilise the latest component technologies at a better cost it does face some unknowns which need to be explored. For example, one of the premises of New Space is to build satellite constellations instead of a single, very large and very expensive geostationary satellite.

If this becomes the case it will mean that satellite design will become a lot more compact and hence more power dense. With the satellite electronics being closer together and having increased power density a new type of satellite design will have to be established. Therefore, it is possible that new failure modes could emerge from having a new satellite design with more integrated and therefore power dense electronics.

Of course, just as with the Traditional Space approach failures need to be made in order to define the appropriate component and system test methods. This will ensure the required degree of reliability for the satellite. Although for New Space lifetimes may not be expected to be that of a 15 years+ geostationary satellite, they will still be expected to have a certain degree of reliability to serve their purpose whilst in space. This is currently estimated to be around 7 years but will ultimately depend on the mission objective.

Space Junk

Another unknown is how much material we can launch into orbit around the Earth until we reach a limit, this is especially important to consider as the amount of unwanted debris starts to build in and around the orbit of Earth. How can we monitor and control this accurately and reliably? We therefore need to develop the technology and space infrastructure to ensure we have a sustainable future operating in Space.

Summary & Conclusions

I personally believe that we are only scratching the surface with what's possible with space infrastructure both inside and outside of orbit around the Earth. It is clear that space is being more commercialised and therefore is growing as a potential future significant market which technology and humanity increasingly rely on.

Therefore, it is vital that component manufacturing and standards maintain pace with disruptive change and evolving markets. It is within this white paper that I hope I can give further focus to this and demonstrate what we are doing to ensure the future sustainability of space component technologies well into the future for decades to come.

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