Design of Power Electronic Converters
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Module: Hardware Design
Lecture 62
Capacitors

Welcome to the course on Design of Power Electronic Converters. We were discussing Hardware Design. In this lecture we are going to see details about Capacitors.

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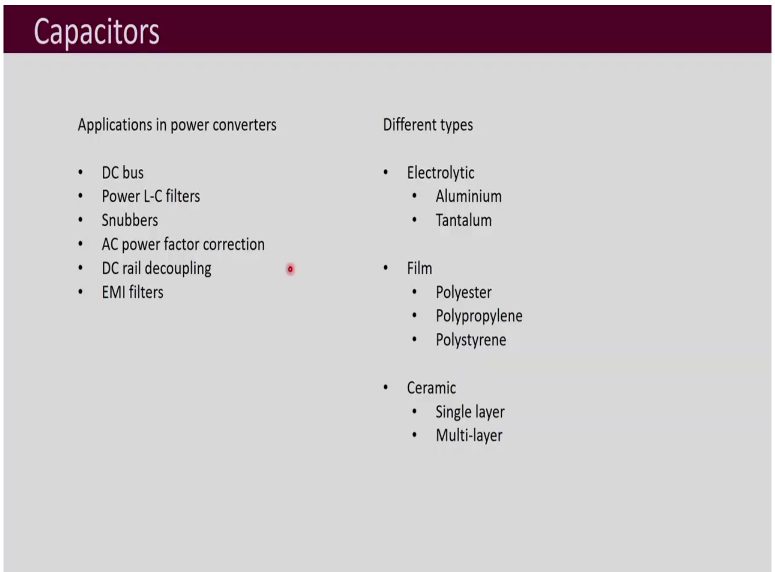

There are numerous places in the power converter where we need to put capacitors. Some of those places are your DC bus. Whenever you need to form a DC bus, let us say if you have a inverter, where the DC bus is being created from a rectifier, so there we need capacitors. Or if we have DC to DC converters, there also we will be needing big, large capacitors. So, DC bus is one place where we need capacitors.

Then Power L-C filters, that may be low frequency filters or relatively little higher frequencies also, but power L-C filters is where we need C. And then, snubbers. If we use R-C snubbers R-C-D snubbers or other types of snubbers, most of them need capacitors. Further AC power factor correction circuits, DC rail decoupling and EMI filters. These are some of the places where we need capacitors in power converters. Apart from that also there may be other roles of capacitor in your power converter.

Now, if we observe these applications, then we see that the way the capacitor is going to play its role is different in different places. When we have the DC bus, the job of the capacitor is to maintain the DC bus voltage. Whereas if let us say if we using it as a filter, if we have an input filter, a big L-C filter, 3-phase L-C filter, let us say, so then it has to filter out the currents, and it will it has to withstand a sinusoidal voltage. So, that capacitor, its requirement are going to be different than what is required by a DC bus capacitor.

Further, if we put capacitance in snubber, so it has to withstand the switching. So fast switching turn on and turn off that takes place, at that time the capacitor also has to charge discharge very quickly and support the turn on process or turn off process of the device. So, what we observe is that in different, different places the capacitor role becomes different, and accordingly the requirement of the capacitor will also be different, means, its specifications are also going to be different.

So, there cannot be only one single type of capacitor, there are many different types of capacitors. Some of the common types of capacitors are electrolytic. In electrolytic also there are sub categories like your Aluminum and Tantalum. Further, we have film capacitors. These can be a polyester, polypropylene and polystyrene. These are some of the types of film capacitors. And then your ceramic capacitors which are sometimes single layers, sometimes multi-layer. So, these are some of the different types of capacitors that are used in power electronic converters.

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Now, let us see some pictures of capacitors. This course is designed with perspective of a beginner in hardware design for power electronic converters. So, I am going to show you pictures of the capacitors, their different types, some of which you might have already seen it or you might have already used and some of which you might not have used or seen.

So, this one should be very familiar to you, these electrolytic capacitors. These are usually used in a power supplies and in DC bus, and is usually the capacitance is large for these electrolytic capacitors. And in that, your another category is your Tantalum caps. So, these are also used in your DC power supply, so regulated power supplies. And this is that through hole package and this is a SMD package of this, so same new tantalum capacitors.

Now, these capacitors, electrolytic caps, these are usually unipolar. That means one of these terminals is positive and another terminal is negative. You cannot connect it in the reverse, that means you cannot apply AC through it. They are mostly not able to withstand that. So, these are unipolar.

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Then next, this is your film capacitors. These are used in your filter applications and they can withstand AC. So, these are pictures of some of these film AC capacitors. You can see that these are also cylindrical in shape, but usually if you see their capacitance value, that will be much lesser than what you get in electrolytic capacitor for the same size. So, this is for low frequency

AC, and if we have a high frequency AC to be applied, then this is picture of one film capacitor which can be used for that purpose.

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Then next we need filters for EMI applications also. There, these kind of capacitors are used. And mostly X and Y caps are used. This, we have discussed before also, I had shown you. So, these, not only are used in EMI filtering applications, other places also, for decoupling also, these kind of capacitors are used, and these are also film capacitors.

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Further, another type of film capacitors, you can see this is a plastic film capacitors and these type of capacitors are mostly used in snubbers. And all these that I showed you in the category of film capacitors, they are not unipolar, that means no polarity of positive and negative is marked beforehand by the manufacturer, and you can apply AC voltage across them.

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Then this one is your ceramic cap. These are very small, small capacitors which also you might have used in your basic electronics lab. So, these are mostly used as decoupling caps or in analog electronic circuits, they are very much used. So, these are also available in your SMD, these small, small chip size or box size of your surface mount device capacitors. So, and these are usually, the value of the capacitances much smaller than your electrolytic or film capacitors.

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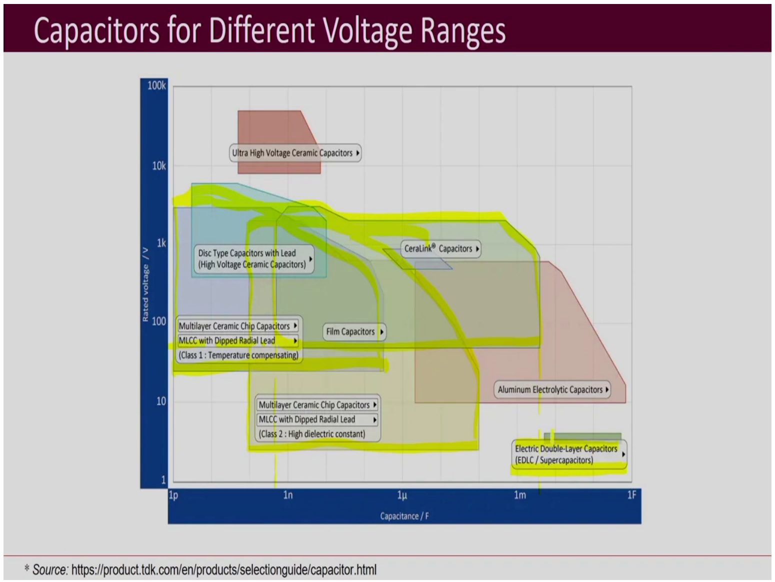

Now, the main specification in capacitors are your voltage rating and the capacitance. The, whenever we hear about capacitor and if we have to get one, so mostly we will be asking that this is the value of the capacitance that I need and for it has to withstand this much amount of voltage. So, when you know that, then which is the type of capacitor which is likely to suit your purpose.

So, this graph it shows between your range of capacitance and your rated voltage range, which type of capacitors are available. So here, you can see that that in this range, that means from your about few micro Farad to about the range of Farads, about a Farad, your aluminium electrolytic capacitors are available, they can be manufactured. And the voltage rating, you can see that it is about, you are starting from about 10s of volts to about 600, 700 V is the range, voltage range in which your aluminium electrolytic capacitors are available.

Then if we see film capacitor, you can see this box of film capacitor. This is the box that is given by the manufacturer. So, this graph is taken by one of the manufacturer of capacitors TDK. So, here, you see that for film capacitor, the voltage range begins slightly higher, about less than 100 volts, and then the voltage range goes up to, around here you can see that about 5 kilo volt. And the range of capacitance, you can observe here, it is from less than nano Farad to about milli Farad, is what is the range where film capacitors are manufactured.

Further, if we see your ceramic capacitors, so ceramic capacitors different types, you can see that this type of the ceramic capacitor, it starts from about a pico Farad to the range is less than micro

Farad. And the voltage range, you can see here that this voltage ranges more than 10 volts to about greater than kilo volts is in which this ceramic capacitor are manufactured. Similarly, you can see for another type of ceramic capacitor what is the range, and then what is the frequency in which it is manufactured.

And also, you might have heard about super capacitor. They can store much more energy than the normal capacitors that we usually use. So, that, you can see here. This ranges from one milli Farad to about a Farad. And although the voltage over here, the range that is given is small. So, with this, you get an idea that which type of capacitor is available in what capacitance range, and what voltage range. Now, let us look into the equivalent circuit of a capacitor. So, when now we hear capacitor, ideally a capacitor should have only capacitance, it should not have any other parasitics. But practically every capacitor will have some parasitics.

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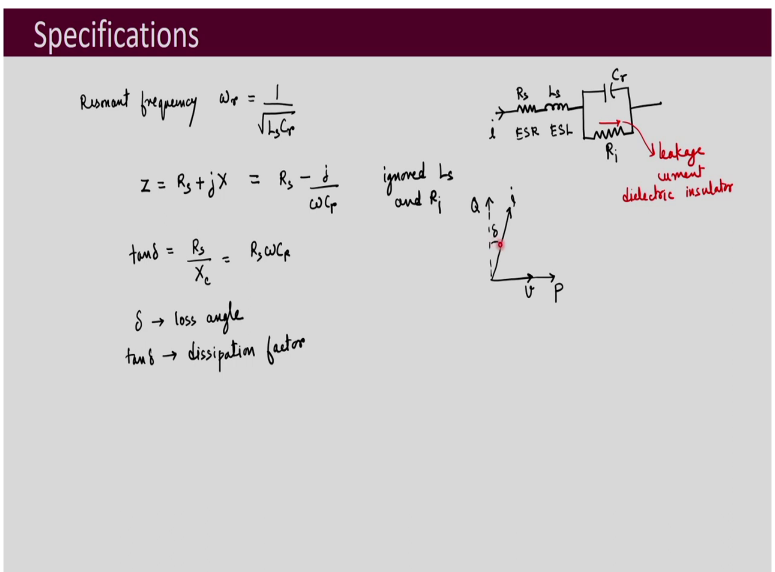

So, the equivalent circuit of a capacitor is usually like this. R_s, this is the ESR, effective series resistance of the capacitor, and L_s is the effective series inductance, L_s, ESL, and C_r is this ideal capacitor, which it should be, and R i is the leakage resistance. Now, when we see this equivalent circuit, then we see that because of this parasitic inductance, there will be a resonant frequency and that resonant frequency will be given by ω_r is equal to root over of L_sC_r.

So, what we observe from here, if we have to find out the impedance of this practical capacitor, then the impedance is going to vary with frequency. So, if we have to write that, so this impedance z, will be equal to R_s plus jX which will be given as R_s - $j\varpi C_r$. Now, here, we have ignored L_s and R_i. We can ignore R_i because usually R_i is very large. So, usually, very less current flows through this R_i.

And that current is called as this leakage current and this is because of the dielectric insulator, the non-ideality of the dielectric insulator. The dielectric should act as a perfect insulator but it does not and there is high resistance associated with it, and some small current flows through it and that is the leakage current. Now, of course, this will lead to some heating and that is going to reduce the lifetime of the capacitor. So, that is not desired. But for the purpose of finding out the impedance, this leakage resistance can be ignored.

And further, we are also ignoring ESL, the effective series inductance. Now, this inductance value of course is a parasitic, it is very small. And for very large range of frequency, which, which is less than your resonant frequency, much less than your resonant frequency, this L_s is small enough so that it can be ignored, the drop associated with it is very small. So, then the impedance can be written as

$R_s - j/\varpi C_r$.

Now, if we see the phasor diagram, so if we have this is the voltage and with it is the real power P and quadrature to that will be the reactive power Q, and if we have to draw the current, so the current will be lying somewhere here, and there is an angle to it that is that angle delta. So, $\tan\delta$ will be equal to R_s/X_C which will be equal to $R_s \varpi C_r$. So, this δ is called as the loss angle, and $\tan\delta$, this is called as the dissipation factor.

Now, this is an important specification in the data sheet of capacitor because as you can see that if you want ideal behavior, then this I should be 90 degrees to V, but that does not happen because of this ESR of the capacitor. And the higher this resistance is greater is this angle δ is going to be, and you can see that the more ESR, the more the loss is going to occur inside the capacitor and more heating, and so more quickly it is likely to get damaged.

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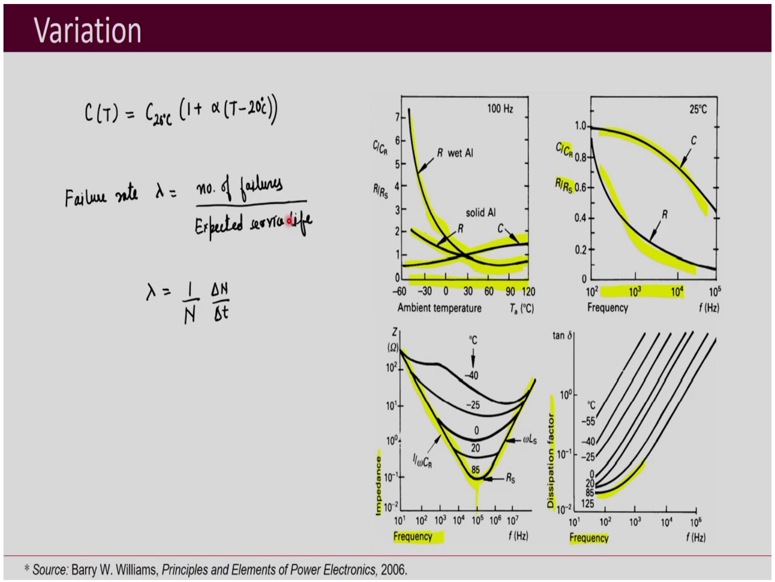

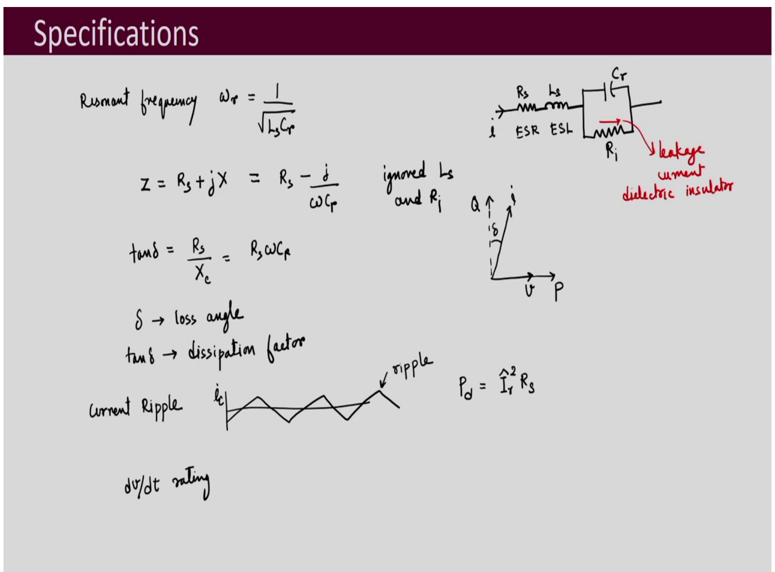

Now, in this graph, it shows the variation of this ESR and the capacitor with respect to temperature and frequency. Now here, you can see that this axis shows temperature and this axis shows your ESR and the capacitor. So, these are for two capacitors it is shown here, aluminium capacitors, different types. So, you can see that that this resistance it decreases with temperature. And somewhere here you can see for some time it is almost like a constant and then again it is increasing, its varying.

And if we see the capacitance, that also we can see here that this also varies with the temperature. So, capacitors, they usually work for a given range of temperature and they do change with temperature. It is not that for all temperature you will be getting a fixed value. So for capacitors, generally as a function of temperature it is given as the capacitance at 20 degrees $C_{20^oC}(1+\alpha(T-20^oC))$. And what is this α? This α is the temperature dependence of capacitor coefficient.

So from here, we observe that usually at a particular temperature, the capacitance will be specified and if you also know the α value, then you can find out at some other temperature what will be the value of the capacitance. So, the thing to be noted is that capacitance does vary with temperature, and you can use capacitors for a given range of temperatures.

Further, here what we see that on x-axis we have got frequency, and on y-axis again we have got the ESR and the capacitor. So, there also we see that this capacitance changes with frequency, and this ESR value also varies with frequency. So again, both resistance and the capacitance, ESR and the capacitance, they vary with frequency.

So, depending on the frequency of use, you have to know that what is mentioned in the data sheet, you may not be getting exactly the same value because you may not be using the capacitor exactly at the frequency at which the manufacturer might have provided the data or might have tested these and obtained the values.

Further, here, this is a graph between the impedance of the capacitor and the frequency. Here also, you see that what is happening is that as frequency is increasing, the capacitance, this impedance is decreasing. So, that is obvious because frequency increases because of the capacitance, you will see a decrease in the impedance.

And this is over here at resonance, so this is your resonant frequency. And then this increases, this impedance is going to increase because after that, the L_s effect will start to dominate. And these graphs shows between dissipation factor tan delta and the frequency. So, this also, we see that with frequency, this is increasing. At higher frequencies, you are going to get higher dissipation factors.

So now, the next important specification in capacitors is the current ripple. You might recall when we discussed buck converter and also H bridge converters, there you saw the nature of the capacitor current. So, the capacitor current, you may recall for your buck converter was something like this, your i c current. So here, this is the nature of the current is that that it has got ripples in it.

Now, its average may be 0, but then it has got an rms value. And this rms current, this continuous charging and discharging of the capacitor that is going to happen, that will lead to some heating in the capacitor because of the ESR that is present. So, your power dissipated corresponding to the ripple current will be equal to this $\hat{I}_r^2 R_s$. Now, whatever the heating that will take place, that will be raising the temperature of the capacitor also. So, this effect is unwanted and only to a certain extent this can be, the capacitor can withstand it.

So accordingly, this ripple current will have a limit. And as we see that this R_s is dependent on temperature and it is also dependent on frequency, so obviously this, then your ripple current limit will also be dependent on frequency and temperature. So, this is an important specification which you should be looking for in the data sheet of a capacitor.

And it depends on your application. If you have a DC bus, then what is the nature of the ripple current, how much is your ripple current reaching up to, you should see the capacitor current waveform, you should find out that and whatever capacitor you choose its ripple current specification should be higher than what is required in your application.

Further another important rating is your dv/dt rating. So, dv/dt rating, this, what it means is that that how fast or how quickly the voltage can change in the capacitor. The capacitor, if you have an AC capacitor then your voltage will be changing through it. And if you have a DC capacitor it is likely to hold, maintain the voltage, it is likely to store lot of energy.

So, in applications like snubbers where your turn on and turn off, in that your capacitor is playing a role, your voltage is supposed to change very quickly through it. So, you have to see that if you choose a capacitor for a snubber, dv/dt rating should be high enough so that your turn on and turn off process can happen properly.

Whereas if you have some other application where you would like to, the capacitor has to maintain the DC bus voltage, so there your voltage through the capacitor is not changing so quickly and your dv/dt rating is not so important for there. So, this dv/dt rating means whatever capacitor that you are using, how quickly does it allow the rate of the change of voltage through it, is an important specification in for capacitors.

Another important specification that you may look for is the life expectancy or the failure rate of the capacitor. So, there is a term called as Failure rate, λ, which is given as a number of failures/expected service life

Now, everything has got a life after which it gets damaged. That is what we generally understand, but how do we quantify that for capacitors.

So, whatever the specifications that are given for the capacitor, the capacitor has to provide that value. If it is not able to do that, or it is deviating from that, so then we can say that that it is degraded or its service life is over. So then, how it is determined is that several different capacitors, let us say a n number of capacitors are taken and for that, then its deviation from those values, those are observed and the number of times it fails that is noted down, and then in what time period it is doing that is also noted.

So there, your if we have got a sample of N, so this λ this will be given

$(1\backslash N)(\Delta N\backslash \Delta t)$,

that means let us say for a chosen capital N values of capacitors, if ΔN failed in Δt period of time, so the failure rate is, accordingly can be obtained from this. And this shows the reliability because this ΔN is a percentage of this total number of samples N that is taken.

And this expected service life, that manufacturers will know that what is the expected service life and from here you get the number of hours or number of times the capacitor is expected to work. So, that is also specified in the data sheet by manufacturers in different ways and you can look for it, for how long the capacitor is going to, is likely to work.

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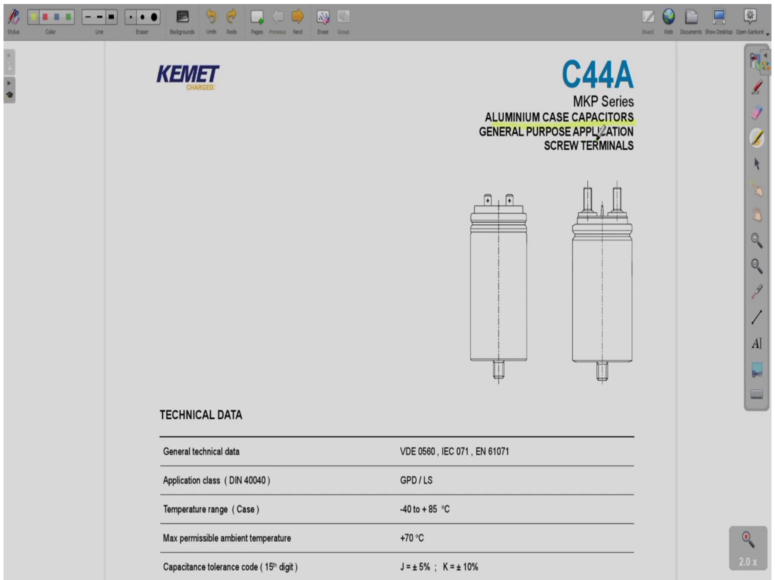

Now, let us look into the data sheets of some of the capacitors. Now this is, this aluminium case capacitor that you can see that that for which this data sheet is.

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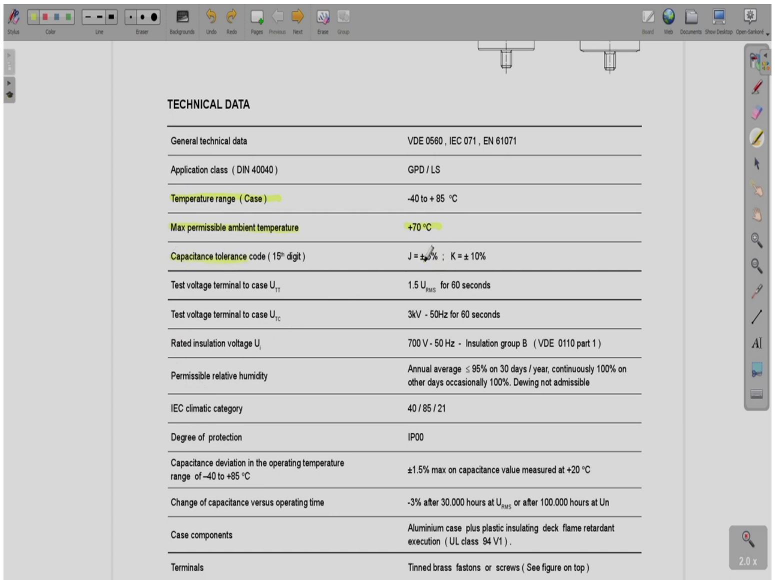

And here you can see that what are the different specifications that are written. The temperature range is provided, and maximum permissible ambient temperature is also given. Then capacitance tolerance, it is given, the code is provided.

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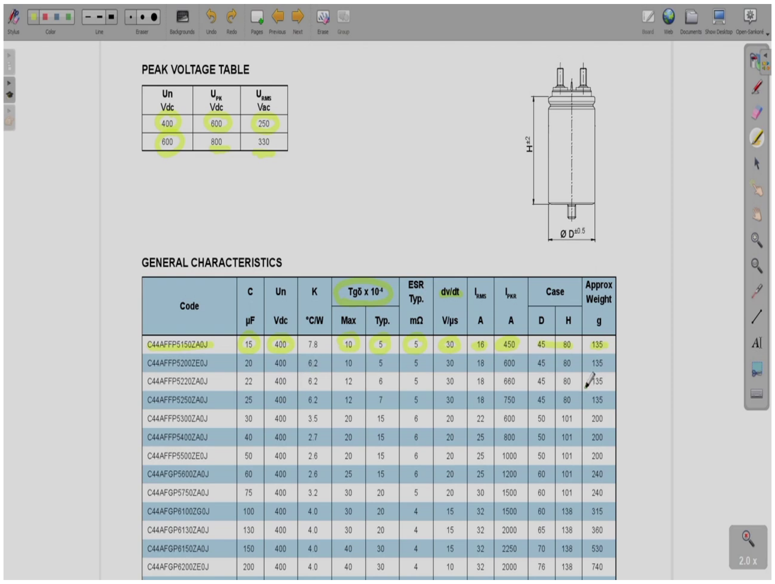

Now, this data sheet is for a series of capacitors, not just for one capacitor. So, for that, the voltage range is specified. You can see that the DC voltage is 400 V, and 600 V. And then the peak voltage is 600 V. And the AC rms voltage is 250 V. Now this, you have to note down, the AC voltage rating, the DC voltage rating, and peak voltage rating. Peak is different peak is something which you can apply for a short period of time. And DC voltage is something which you can apply continuously.

So, these ratings are different and so that is what you have to note down is whether according to what you need or not when you choose a capacitor. Then further, if we see here, the manufacturer has given one table. Now, this is for the series, but the values they have given is like this, this one is for 15 μF. And the DC voltage is 400 V. And then, you can see here, this is given, your dissipation factor, that those values are given, the maximum and the typical. Then the ESR value is also given.

Further, what we see here is it is dv/dt rating, it is 30 volt per μs. The I rms current, what is the rms current that this capacitor can withstand, and the peak of that current, peak current it can withstand only for very short period of time, that is 450 A. And further, these are the dimensions and your weight of the capacitor that is provided. And here you can see that this is ^{o}C/W, so it is related to your temperature. So, these are some of the important parameters that you can see, specifications that you have to note down for the for choosing the capacitor.

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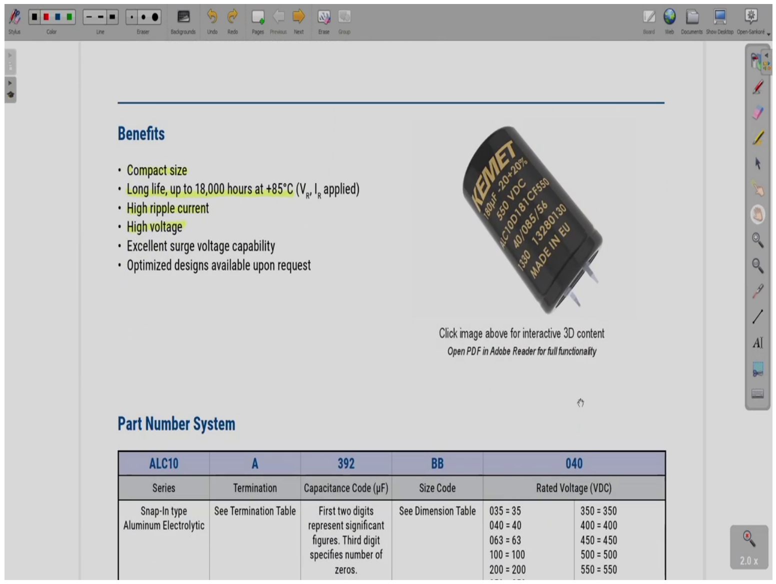

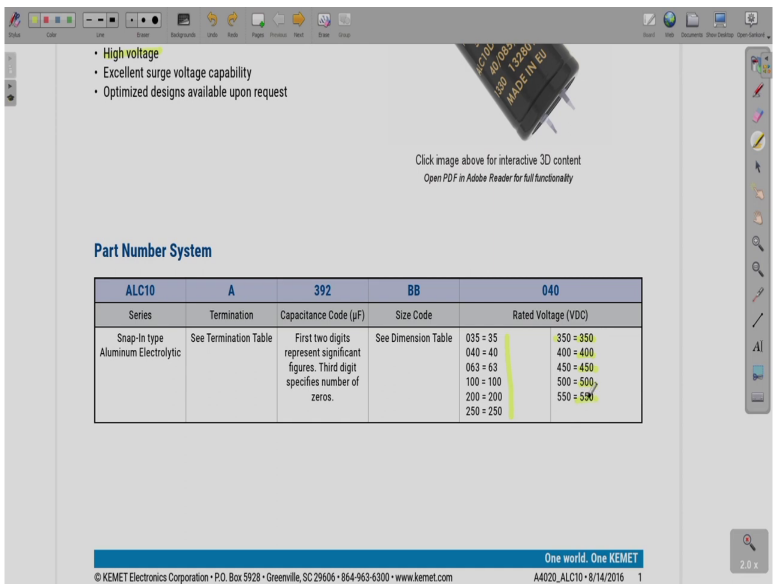

Now, let us see the data sheet of electrolytic capacitor. So, this is an aluminium electrolytic capacitor and here you can see that this service hours, the life is given as up to 18,000 hours for 85 ºC, that is what the manufacturer has written. Then high ripple current, high voltage, compact size, this is what the manufacturer has written as the benefits. And this is the picture of the capacitor. Now, you can see here that further, for this series, this voltage range, the V_{DC} is given that these capacitors come in 350, 400, 450, 500 and 550 V.

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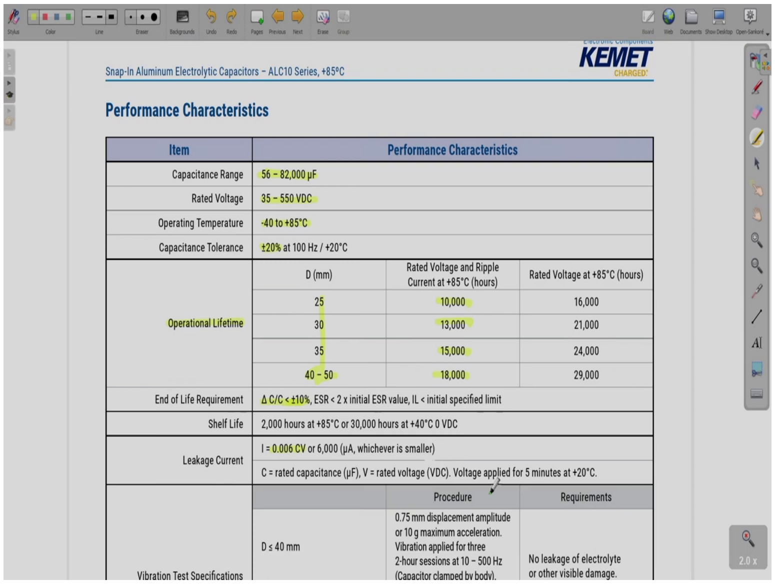
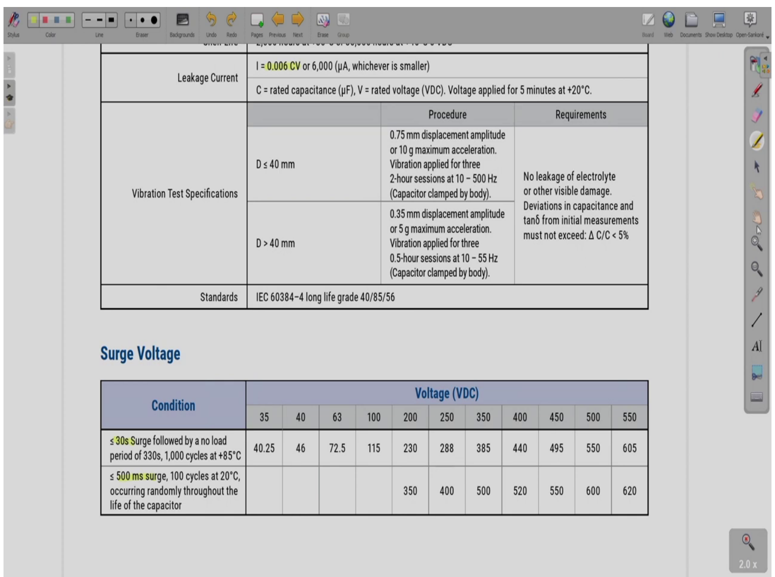


Snap-In Aluminum Electrolytic Capacitors – ALC10 Series, +85ºC

KEMET CHARGED

Performance Characteristics

Item	Performance Characteristics		
Capacitance Range	56 – 82,000 µF		
Rated Voltage	35 – 550 VDC		
Operating Temperature	-40 to +85°C		
Capacitance Tolerance	±20% at 100 Hz / +20°C		
Operational Lifetime	D (mm)	Rated Voltage and Ripple Current at +85°C (hours)	Rated Voltage at +85°C (hours)
	25	10,000	16,000
	30	13,000	21,000
	35	15,000	24,000
	40 – 50	18,000	29,000
End of Life Requirement	Δ C/C < ±10%, ESR < 2 x initial ESR value, IL < initial specified limit		
Shelf Life	2,000 hours at +85°C or 30,000 hours at +40°C 0 VDC		
Leakage Current	I = 0.006 CV or 6,000 (µA, whichever is smaller)		
	C = rated capacitance (µF), V = rated voltage (VDC). Voltage applied for 5 minutes at +20°C.		
Vibration Test Specifications		Procedure	Requirements
	D ≤ 40 mm	0.75 mm displacement amplitude or 10 g maximum acceleration. Vibration applied for three 2-hour sessions at 10 – 500 Hz (Capacitor clamped by body).	No leakage of electrolyte or other visible damage.



Leakage Current	I = 0.006 CV or 6,000 (µA, whichever is smaller)		
	C = rated capacitance (µF), V = rated voltage (VDC). Voltage applied for 5 minutes at +20°C.		
Vibration Test Specifications		Procedure	Requirements
	D ≤ 40 mm	0.75 mm displacement amplitude or 10 g maximum acceleration. Vibration applied for three 2-hour sessions at 10 – 500 Hz (Capacitor clamped by body).	No leakage of electrolyte or other visible damage. Deviations in capacitance and tanδ from initial measurements must not exceed: Δ C/C < 5%
	D > 40 mm	0.35 mm displacement amplitude or 5 g maximum acceleration. Vibration applied for three 0.5-hour sessions at 10 – 55 Hz (Capacitor clamped by body).	
Standards	IEC 60384–4 long life grade 40/85/56		

Surge Voltage

Condition	Voltage (VDC)										
	35	40	63	100	200	250	350	400	450	500	550
≤ 30s Surge followed by a no load period of 330s, 1,000 cycles at +85°C	40.25	46	72.5	115	230	288	385	440	495	550	605
≤ 500 ms surge, 100 cycles at 20°C, occurring randomly throughout the life of the capacitor					350	400	500	520	550	600	620

Now, you can note down here the capacitance range for the series of capacitor is given as to 56 to 82,000 μF. And the rated voltage is also given as 35 to 550-volt DC for the series. And the temperature range is also provided. And the capacitance tolerance is given as +/- 20º at 100 Hz. Then you can see that here this operational lifetime is provided for these different dimensions in this series, how many hours of lifetime it has got.

And then end of life requirement, what do we mean by end of life requirement, is ΔC/C should be less than +/-10 %. That is what is given, and the shelf life is also provided here. Then further, the leakage current that is given here, it is, this is whatever is smaller of these two that is what is written as the leakage current. So, it has to be 0.006 CV or 6,000 A, which is the rated capacitance in µF, and V is the rated voltage.

Then further, some vibration test specifications are also provided by the manufacturer. And what we see further is the surge voltage, means if you apply for a short duration of time, a surge voltage appears, then what could be that voltage a maximum voltage, surge voltage that the capacitor can withstand, those specifications are also provided over here, that also you can see here what is the voltage that is given. And how much time it is applied for, that is also provided, the condition of the surge voltage is also provided.

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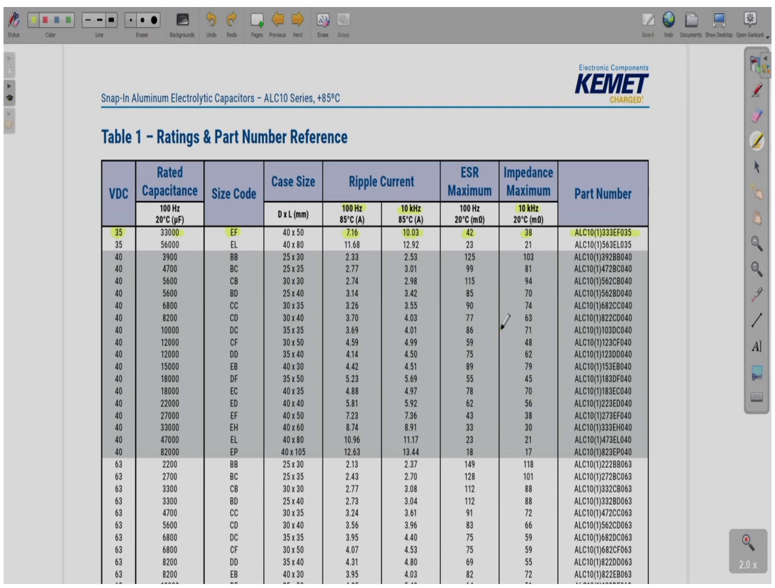

Snap-In Aluminum Electrolytic Capacitors – ALC10 Series, +85ºC

Table 1 – Ratings & Part Number Reference

VDC	Rated Capacitance	Size Code	Case Size	Ripple Current		ESR Maximum	Impedance Maximum	Part Number
	100 Hz 20°C (µF)		D x L (mm)	100 Hz 85°C (A)	10 kHz 85°C (A)	100 Hz 20°C (mΩ)	10 kHz 20°C (mΩ)	
35	33000	EF	40 x 50	7.16	10.03	42	38	ALC10(1)333EF035
35	56000	EL	40 x 80	11.68	12.92	23	21	ALC10(1)563EL035
40	3900	BB	25 x 30	2.33	2.53	125	103	ALC10(1)392BB040
40	4700	BC	25 x 35	2.77	3.01	99	81	ALC10(1)472BC040
40	5600	CB	30 x 30	2.74	2.98	115	94	ALC10(1)562CB040
40	5600	BD	25 x 40	3.14	3.42	85	70	ALC10(1)562BD040
40	6800	CC	30 x 35	3.26	3.55	90	74	ALC10(1)682CC040
40	8200	CD	30 x 40	3.70	4.03	77	63	ALC10(1)822CD040
40	10000	DC	35 x 35	3.69	4.01	86	71	ALC10(1)103DC040
40	12000	CF	30 x 50	4.59	4.99	59	48	ALC10(1)123CF040
40	12000	DD	35 x 40	4.14	4.50	75	62	ALC10(1)123DD040
40	15000	EB	40 x 30	4.42	4.51	89	79	ALC10(1)153EB040
40	18000	DF	35 x 50	5.23	5.69	55	45	ALC10(1)183DF040
40	18000	EC	40 x 35	4.88	4.97	78	70	ALC10(1)183EC040
40	22000	ED	40 x 40	5.81	5.92	62	56	ALC10(1)223ED040
40	27000	EF	40 x 50	7.23	7.36	43	38	ALC10(1)273EF040
40	33000	EH	40 x 60	8.74	8.91	33	30	ALC10(1)333EH040
40	47000	EL	40 x 80	10.96	11.17	23	21	ALC10(1)473EL040
40	82000	EP	40 x 105	12.63	13.44	18	17	ALC10(1)823EP040
63	2200	BB	25 x 30	2.13	2.37	149	118	ALC10(1)222BB063
63	2700	BC	25 x 35	2.43	2.70	128	101	ALC10(1)272BC063
63	3300	CB	30 x 30	2.77	3.08	112	88	ALC10(1)332CB063
63	3300	BD	25 x 40	2.73	3.04	112	88	ALC10(1)332BD063
63	4700	CC	30 x 35	3.24	3.61	91	72	ALC10(1)472CC063
63	5600	CD	30 x 40	3.56	3.96	83	66	ALC10(1)562CD063
63	6800	DC	35 x 35	3.95	4.40	75	59	ALC10(1)682DC063
63	6800	CF	30 x 50	4.07	4.53	75	59	ALC10(1)682CF063
63	8200	DD	35 x 40	4.31	4.80	69	55	ALC10(1)822DD063
63	8200	EB	40 x 30	3.95	4.03	82	72	ALC10(1)822EB063

Further, in this data sheet, you can see that for this series, these are the specifications that are given, that is for 35 V DC, what is the size code and what is the part number. Let us say if this is the part number that we are looking for, then you see that the capacitance is this value at 100 Hz and 20º C, and the ripple current is 7.16 A at 100 Hz, and it is 10.03 at 10 kHz. So, as I told you, that ripple current is dependent on the frequency.

So, you can see here that two different specifications of ripple current are given for two different frequencies. And then the ESR value is also provided. And the maximum impedance, at 10 kHz that is also given. So, like that you can look through the whole data sheet of these kind of capacitors and then look for the values that is required for your application and choose the one that is suitable.

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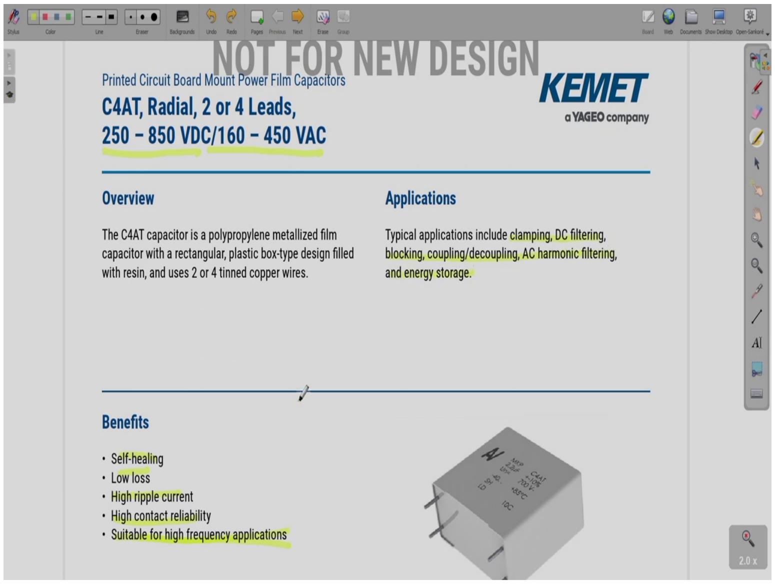

Now, this is a data sheet of another film capacitor. And you can see here that this is the range of voltage in which this capacitor can be found out, that is to 250 to 850 V DC, and 160 to 450 V AC. And you can see here that again the benefits of these, of this capacitor is written by the manufacturer, and they have also written that this is suitable for high frequency applications. And the typical application of the capacitor for which this data sheet is, you can see here that is also mentioned by the manufacturer.

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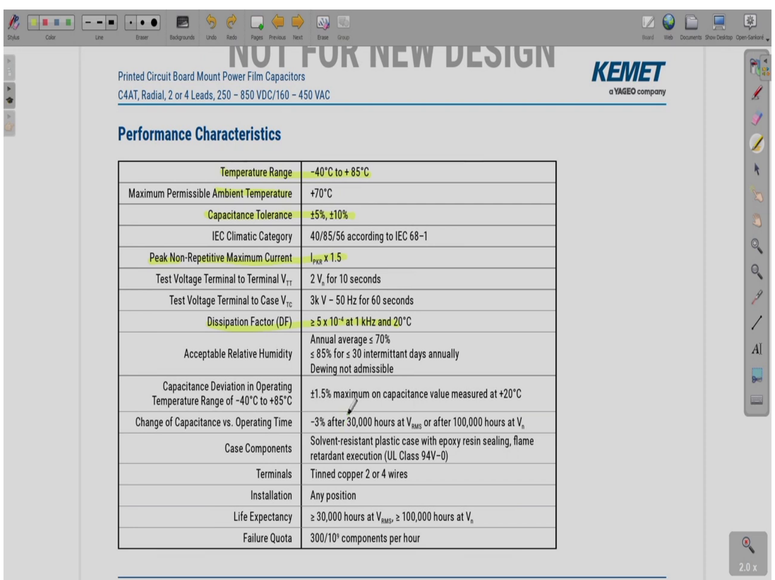

Now here, you can see that again temperature range, ambient temperature capacitance, tolerance values, and then the peak non-repetitive maximum current, these things, your dissipation factor, these are mentioned by the manufacturer. There are several specifications that are given. You can go through the data sheet and most of them are self-explanatory. And suppose some of the specifications are not able to understand what they have written, you can go to the application notes by the manufacturers, and then usually they will describe what that specification means.

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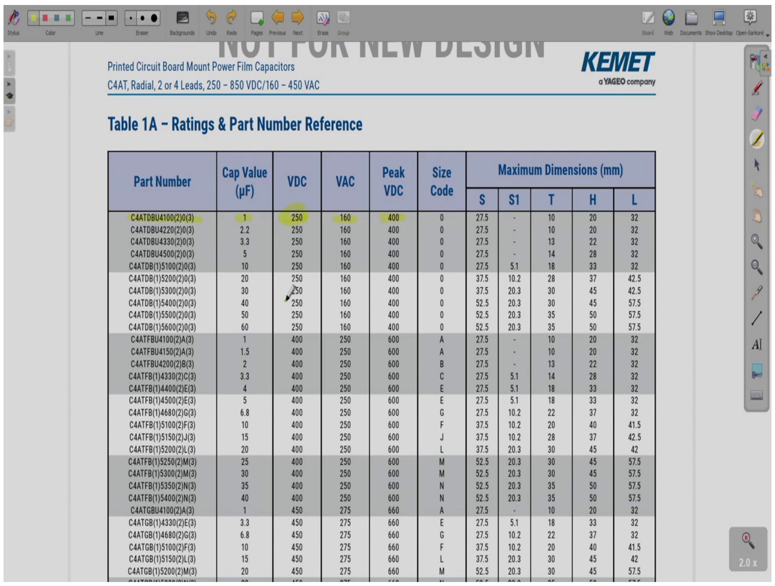
NOT FOR NEW DESIGN

Printed Circuit Board Mount Power Film Capacitors
C4AT, Radial, 2 or 4 Leads, 250 – 850 VDC/160 – 450 VAC

KEMET
a YAGEO company

Table 1A – Ratings & Part Number Reference

Part Number	Cap Value (µF)	VDC	VAC	Peak VDC	Size Code	Maximum Dimensions (mm)				
						S	S1	T	H	L
C4ATDBU4100(2)0(3)	1	250	160	400	0	27.5	-	10	20	32
C4ATDBU4220(2)0(3)	2.2	250	160	400	0	27.5	-	10	20	32
C4ATDBU4330(2)0(3)	3.3	250	160	400	0	27.5	-	13	22	32
C4ATDBU4500(2)0(3)	5	250	160	400	0	27.5	-	14	28	32
C4ATDB(1)5100(2)0(3)	10	250	160	400	0	27.5	5.1	18	33	32
C4ATDB(1)5200(2)0(3)	20	250	160	400	0	37.5	10.2	28	37	42.5
C4ATDB(1)5300(2)0(3)	30	250	160	400	0	37.5	20.3	30	45	42.5
C4ATDB(1)5400(2)0(3)	40	250	160	400	0	52.5	20.3	30	45	57.5
C4ATDB(1)5500(2)0(3)	50	250	160	400	0	52.5	20.3	35	50	57.5
C4ATDB(1)5600(2)0(3)	60	250	160	400	0	52.5	20.3	35	50	57.5
C4ATFBU4100(2)A(3)	1	400	250	600	A	27.5	-	10	20	32
C4ATFBU4150(2)A(3)	1.5	400	250	600	A	27.5	-	10	20	32
C4ATFBU4200(2)B(3)	2	400	250	600	B	27.5	-	13	22	32
C4ATFB(1)4330(2)C(3)	3.3	400	250	600	C	27.5	5.1	14	28	32
C4ATFB(1)4400(2)E(3)	4	400	250	600	E	27.5	5.1	18	33	32
C4ATFB(1)4500(2)E(3)	5	400	250	600	E	27.5	5.1	18	33	32
C4ATFB(1)4680(2)G(3)	6.8	400	250	600	G	27.5	10.2	22	37	32
C4ATFB(1)5100(2)F(3)	10	400	250	600	F	37.5	10.2	20	40	41.5
C4ATFB(1)5150(2)J(3)	15	400	250	600	J	37.5	10.2	28	37	42.5
C4ATFB(1)5200(2)L(3)	20	400	250	600	L	37.5	20.3	30	45	42
C4ATFB(1)5250(2)M(3)	25	400	250	600	M	52.5	20.3	30	45	57.5
C4ATFB(1)5300(2)M(3)	30	400	250	600	M	52.5	20.3	30	45	57.5
C4ATFB(1)5350(2)N(3)	35	400	250	600	N	52.5	20.3	35	50	57.5
C4ATFB(1)5400(2)N(3)	40	400	250	600	N	52.5	20.3	35	50	57.5
C4ATGBU4100(2)A(3)	1	450	275	660	A	27.5	-	10	20	32
C4ATGB(1)4330(2)E(3)	3.3	450	275	660	E	27.5	5.1	18	33	32
C4ATGB(1)4680(2)G(3)	6.8	450	275	660	G	27.5	10.2	22	37	32
C4ATGB(1)5100(2)F(3)	10	450	275	660	F	37.5	10.2	20	40	41.5
C4ATGB(1)5150(2)L(3)	15	450	275	660	L	37.5	20.3	30	45	42
C4ATGB(1)5200(2)M(3)	20	450	275	660	M	52.5	20.3	30	45	57.5

Now here further, again you see that for this data sheet here what is given is the capacitance value, VDC, VAC, peak VDC, which is higher than this VDC value, that is given by the manufacturer.

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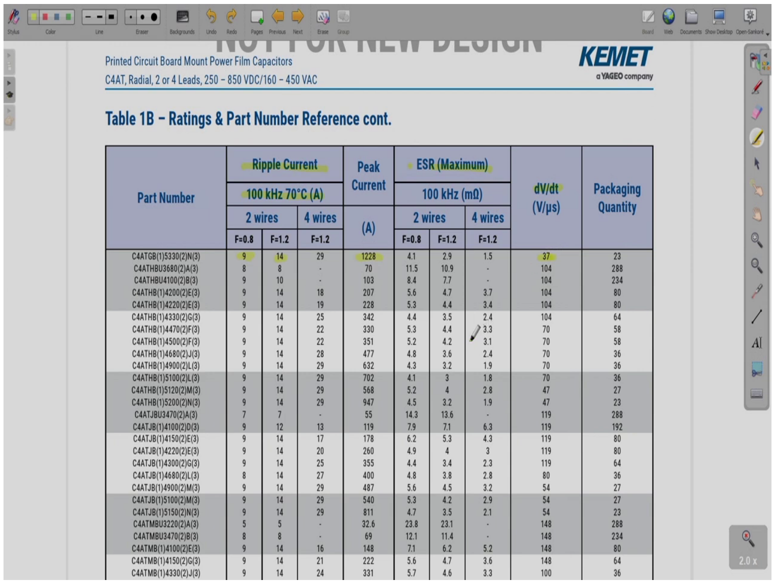

Printed Circuit Board Mount Power Film Capacitors
C4AT, Radial, 2 or 4 Leads, 250 – 850 VDC/160 – 450 VAC

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Table 1B – Ratings & Part Number Reference cont.

Part Number	Ripple Current 100 kHz 70°C (A)			Peak Current (A)	ESR (Maximum) 100 kHz (mΩ)			dV/dt (V/µs)	Packaging Quantity
	2 wires		4 wires		2 wires		4 wires		
	F=0.8	F=1.2	F=1.2		F=0.8	F=1.2	F=1.2		
C4ATGB(1)5330(2)N(3)	9	14	29	1228	4.1	2.9	1.5	37	23
C4ATHBU3680(2)A(3)	8	8	-	70	11.5	10.9	-	104	288
C4ATHBU4100(2)B(3)	9	10	-	103	8.4	7.7	-	104	234
C4ATHB(1)4200(2)E(3)	9	14	18	207	5.6	4.7	3.7	104	80
C4ATHB(1)4220(2)E(3)	9	14	19	228	5.3	4.4	3.4	104	80
C4ATHB(1)4330(2)G(3)	9	14	25	342	4.4	3.5	2.4	104	64
C4ATHB(1)4470(2)F(3)	9	14	22	330	5.3	4.4	3.3	70	58
C4ATHB(1)4500(2)F(3)	9	14	22	351	5.2	4.2	3.1	70	58
C4ATHB(1)4680(2)J(3)	9	14	28	477	4.8	3.6	2.4	70	36
C4ATHB(1)4900(2)L(3)	9	14	29	632	4.3	3.2	1.9	70	36
C4ATHB(1)5100(2)L(3)	9	14	29	702	4.1	3	1.8	70	36
C4ATHB(1)5120(2)M(3)	9	14	29	568	5.2	4	2.8	47	27
C4ATHB(1)5200(2)N(3)	9	14	29	947	4.5	3.2	1.9	47	23
C4ATJBU3470(2)A(3)	7	7	-	55	14.3	13.6	-	119	288
C4ATJB(1)4100(2)D(3)	9	12	13	119	7.9	7.1	6.3	119	192
C4ATJB(1)4150(2)E(3)	9	14	17	178	6.2	5.3	4.3	119	80
C4ATJB(1)4220(2)E(3)	9	14	20	260	4.9	4	3	119	80
C4ATJB(1)4300(2)G(3)	9	14	25	355	4.4	3.4	2.3	119	64
C4ATJB(1)4680(2)L(3)	8	14	27	400	4.8	3.8	2.8	80	36
C4ATJB(1)4900(2)M(3)	9	14	29	487	5.6	4.5	3.2	54	27
C4ATJB(1)5100(2)M(3)	9	14	29	540	5.3	4.2	2.9	54	27
C4ATJB(1)5150(2)N(3)	9	14	29	811	4.7	3.5	2.1	54	23
C4ATMBU3220(2)A(3)	5	5	-	32.6	23.8	23.1	-	148	288
C4ATMBU3470(2)B(3)	8	8	-	69	12.1	11.4	-	148	234
C4ATMB(1)4100(2)E(3)	9	14	16	148	7.1	6.2	5.2	148	80
C4ATMB(1)4150(2)G(3)	9	14	21	222	5.6	4.7	3.6	148	64
C4ATMB(1)4330(2)J(3)	9	14	24	331	5.7	4.6	3.3	100	36

Further, here again you see that this ripple current is specified by the manufacturer. And the peak current for short duration, what the capacitor can withstand, the ESR of the capacitor, the dv/dt rating, this is also given by this, by the manufacturer.

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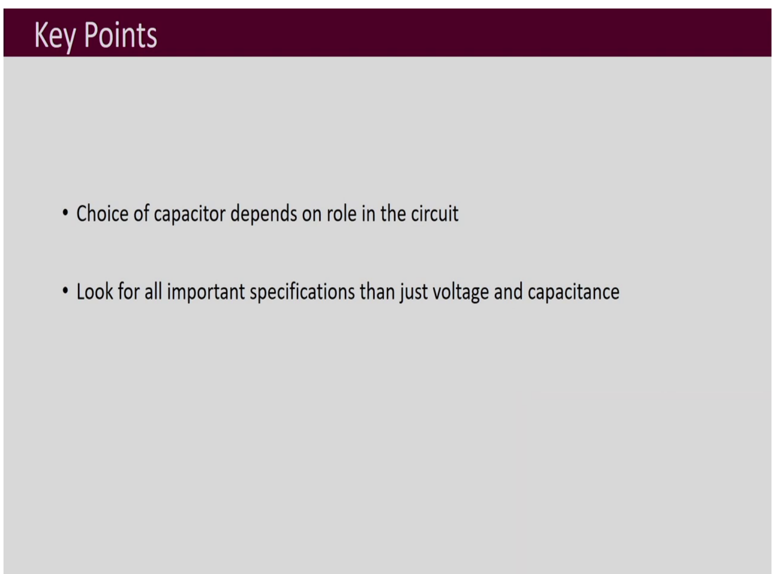

So, the key points of this lecture are that that your choice of capacitor depends on the role in the circuit. Your specifications, what you need, that you have to decide, and accordingly you have to choose the particular type of capacitor that is going to be suitable. And you should look for all important specifications for your application and not just the voltage and the value of capacitance. Thank you.