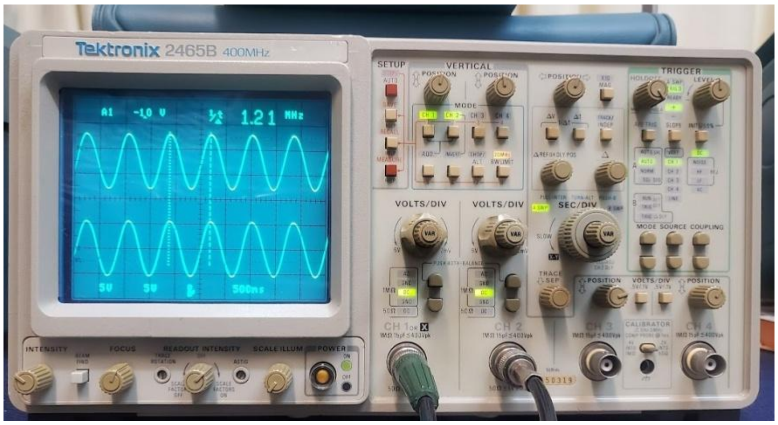
Tek Oscilloscope 2465B: The Power Supply's Electrolytic Capacitors - The Alkaline Shift.

Dr. H. Holden Jan. 2025.



Background:

I have produced a number of articles about the 2465B scope in the past, with view to keeping these scopes running. What is so special about this particular scope that emerged in the late 1980's era? This scope is an extraordinary machine. It is basically an Analog scope but with a digital supporting infrastructure. Because of this it has many features of a Digital scope, but with none of the sampling and aliasing issues of a digital scope.

The 2465B has calibrated frequency, time and voltage Cursors and a memory for the scope's panel settings. An on screen digital display too, yet otherwise, it behaves as an Analog scope.

The scope was rated to a bandwidth of 400 MHz, but that is an understatement. Testing with a levelled Sine Wave generator on the 50 Ohm input, the 2465B is flat to 400MHz and only 3dB down in amplitude by about 600 to 650MHz. Its trigger circuits are so good that you can actually visualise and lock a 900MHz waveform. Of course at that frequency, the amplitude calibration is meaningless. Still the scope is not suddenly "blind above its rated bandwidth"

I have used the 2465B in the past to diagnose and repair UHF TV tuners. It can also be configured for 4 channel use, which comes in very handy fault finding logic circuits.

The scope is a masterpiece of Application Specific ICs (ASIC). Tek called them Hybrids. That is right, there is no such thing as a scope built from "off the shelf parts" that can match a 2465B.

Tek optimized every stage and function with a dedicated ASICs and other IC's they designed themselves. The design of the main board, a multi-layer board, with the ASICs (photo above) is nothing short of awe inspiring.

Tek also designed and manufactured the CRT, a highly complex process. It is a shame that no company in the World now manufactures or can repair CRTs. The CRT in the 2465B could only be described as a Masterpiece of Electron Optics. The CRT had evolved to its peak of perfection before being rendered obsolete by the year 2000. On inspection of this CRT, it is a jaw-dropping extravaganza of precision Metallurgy, Glasswork and Phosphor and the complex industrial processes that created it.

Articles I have written on the 2465B scope so far:

This one looked at the Battery backed up non-volatile SRAM issues in the scope and replacing these with FRAM as an option:

https://www.worldphaco.com/uploads/TEKTRONIX_2465b_OSCILLOSCOPE_CALIBRATION___REPOWERING_THE_DS1225.pdf

This article looked at repairs to the A5 board; the problem had crippled a number of 2465B's:

https://www.worldphaco.com/uploads/TEKTRONIX_2465b_OSCILLOSCOPE_A5_BOARD_REPAIR.pdf

This article looked at an inter-track leakage issue caused by Tin Whiskers which had caused one scope repairer in the USA to put a number of main boards aside and label them unrepairable:

https://www.worldphaco.com/uploads/TEKTRONIX_2465B_OSCILLOSCOPE_MAIN_BOARD_INTER-TRACK_LEAKAGE..pdf

This article addresses a failure mode endemic to the Horizontal Output IC. Unfortunately power cycling and thermal effects result in de-lamination inside the IC body:

https://www.worldphaco.com/uploads/The%20U800%20Problem-%20Tek%202465B.pdf

This article returned to the issue of the battery powered non-volatile SRAM, the DS1225. I immortalized the the DS1225 with a Mechanical Engineering Solution:

https://worldphaco.com/uploads/THE%20DALLAS%20DS1225-ReMastered..pdf

In addition an article related to other Tek scopes such as the Tek 464 and in the general area of the Vertical Amplifier Circuitry and Vertical Amplifier calibration:

https://www.worldphaco.com/uploads/TEKTRONIX_OSCILLOSCOPES.pdf

THE 2465B's PSU:

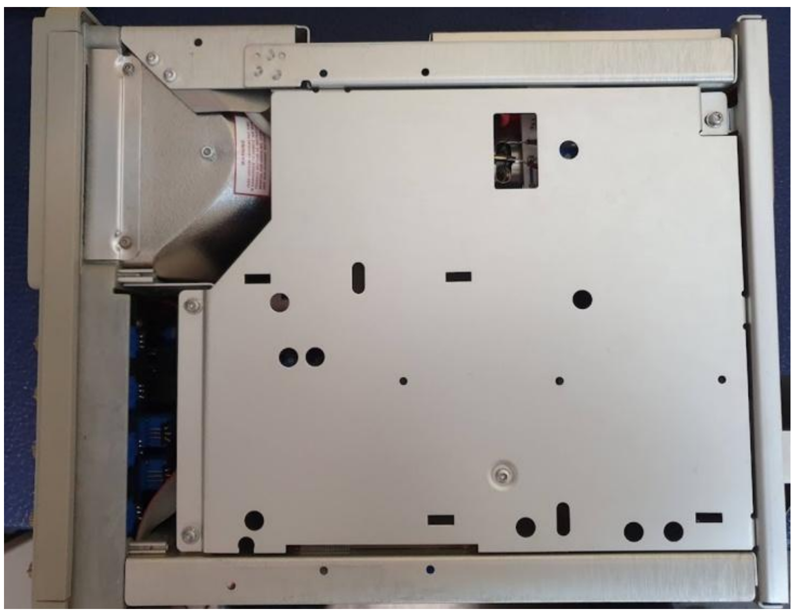
The topic of this article presented here is focussed on the scope's PSU. It is a mixed Switching and Analog power supply. The question always comes up, especially for a scope made in the late 1980's: Do all the power supply Electrolytic Capacitors in my scope need changing, now that they are 35 years old?

It is an interesting question, especially for a scope where the designers sought in the first instance to use the highest quality parts, including the Electrolytic Capacitors.

The reason this article was created is that I retrieved one of my 2465B spare scopes from storage. It was the oldest one of the 2465B's I have and it was made in 1989.

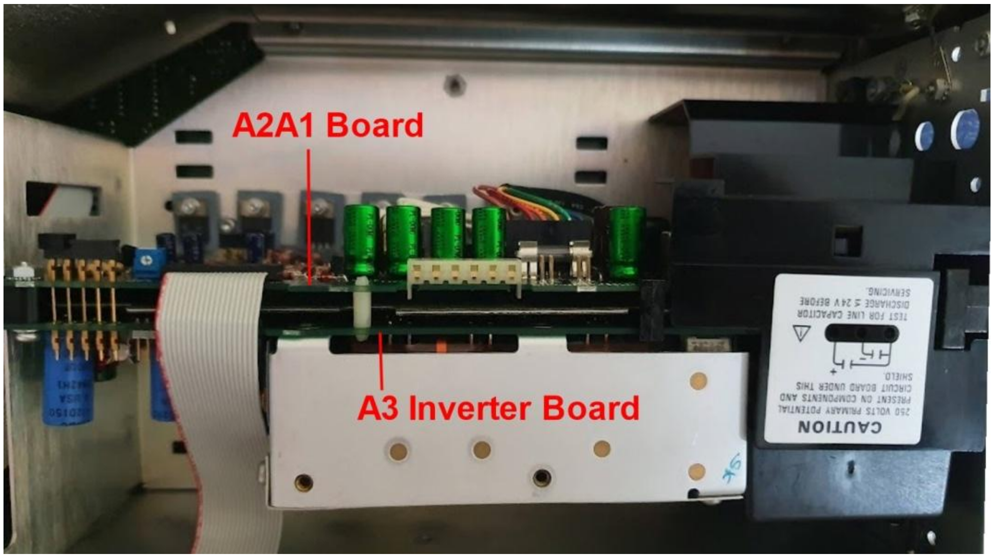
The last time I powered this one, about a year before, it was working 100%. This time I powered it and it was totally dead. No sign of life at all. I did the usual initial checks and found that power was being applied and and none of the fuses were blown. What could have caused it to fail?

The power supply unit is buried inside the scope. Once the scope is slid out of its outer shell you are greeted with a top screening cover:



Once the cover is removed there is some access to the power supply unit. Two boards are sandwiched together with a series of long Gold plated plug-pins that connect the two PCBs.

The lower A3 inverter PCB is the one which largely processes the Line voltage. There are some of the Line Input Filter circuit components on the upper A2A1 board where the Power ON-OFF switch, NTC surge suppressor components are and X2 capacitors are located. The A2A1 board primarily handles the low voltage side of things.



With the PSU unit mounted in the scope the access to the A3 inverter board is very poor. An aluminium shield partially covers it too. It is not practical to gain access to most of the PCB's components with it initially.

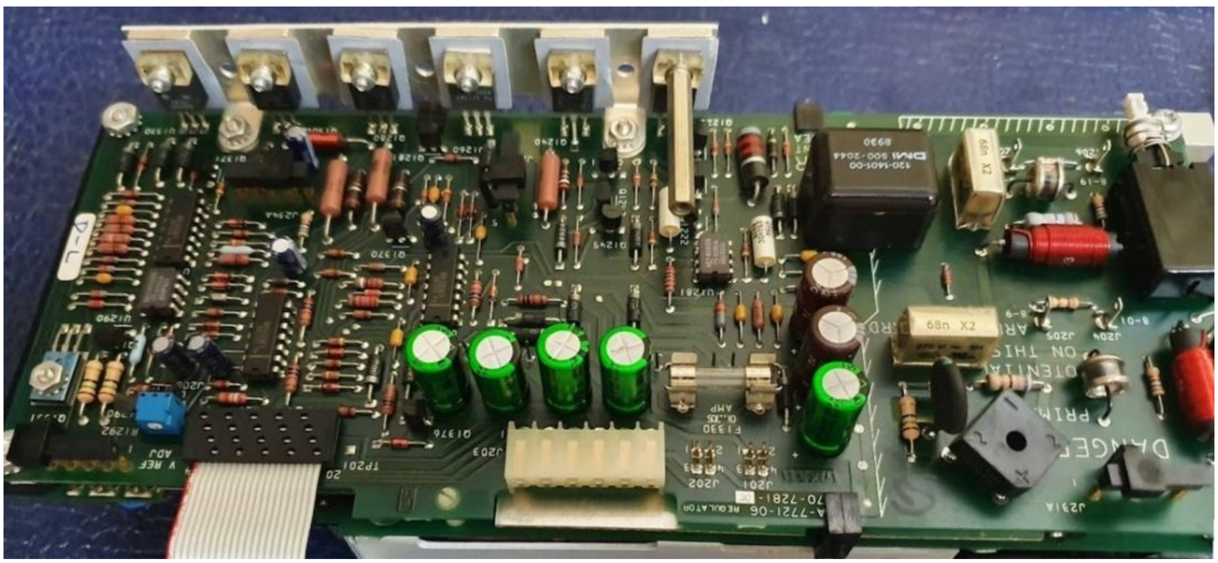
One solution is to remove the whole assembly, attach flying wires to various test points and re-fit the PSU to the scope. In many cases (not all) it is better if possible to diagnose the PSU with it connected to its standard loads in the scope. This is the case with most SMPS repairs unless specific dummy loads are created. Another method is extension leads for the supply's output connectors if they are on hand.

Notice the Green jacket 100uF/25V Electrolytic Capacitors. These are high quality 105 degC Nichicon parts. There are three on the A3 board and five on the A2A1 board. A year or two later Tek moved to 100uF/50V Nichicon types with a brown jacket. Clearly they had a lot of confidence in these Japanese capacitors.

The blue jacket capacitors (which sometimes have a clear jacket in the2465B scope) are American made 180uF 40V and 250uF 20V 105 Degree C types. More will be said about both types of capacitor later.

The A2A1 voltage regulator board is shown below:

The two brown jacket electrolytic capacitors on this board are 10uF/100V parts which seldom if ever give any trouble. The smaller electrolytic capacitors seen with the black jackets are 1uF/50v Bipolar types. They appear very reliable. If they require replacement I recommend using 1uF/63v MKT film capacitors instead. The two small dark blue jacket capacitors are 47uF/25V Nichicon types that in my scopes at least, are still ok. On the right hand side where the Line power is initially processed and rectified, are a pair of Rifa 0.068uF X2 capacitors, more will be said about these later.



A3 Inverter board below is a 1990 vintage specimen and they had moved to 100uF/50V brown jacket Nichicon capacitors .The view with the shield removed. This board also contains some Rifa Y capacitors:

The early 1989 vintage PSU's tended to have the 100uF/25v Green jacket Nichicon capacitors:

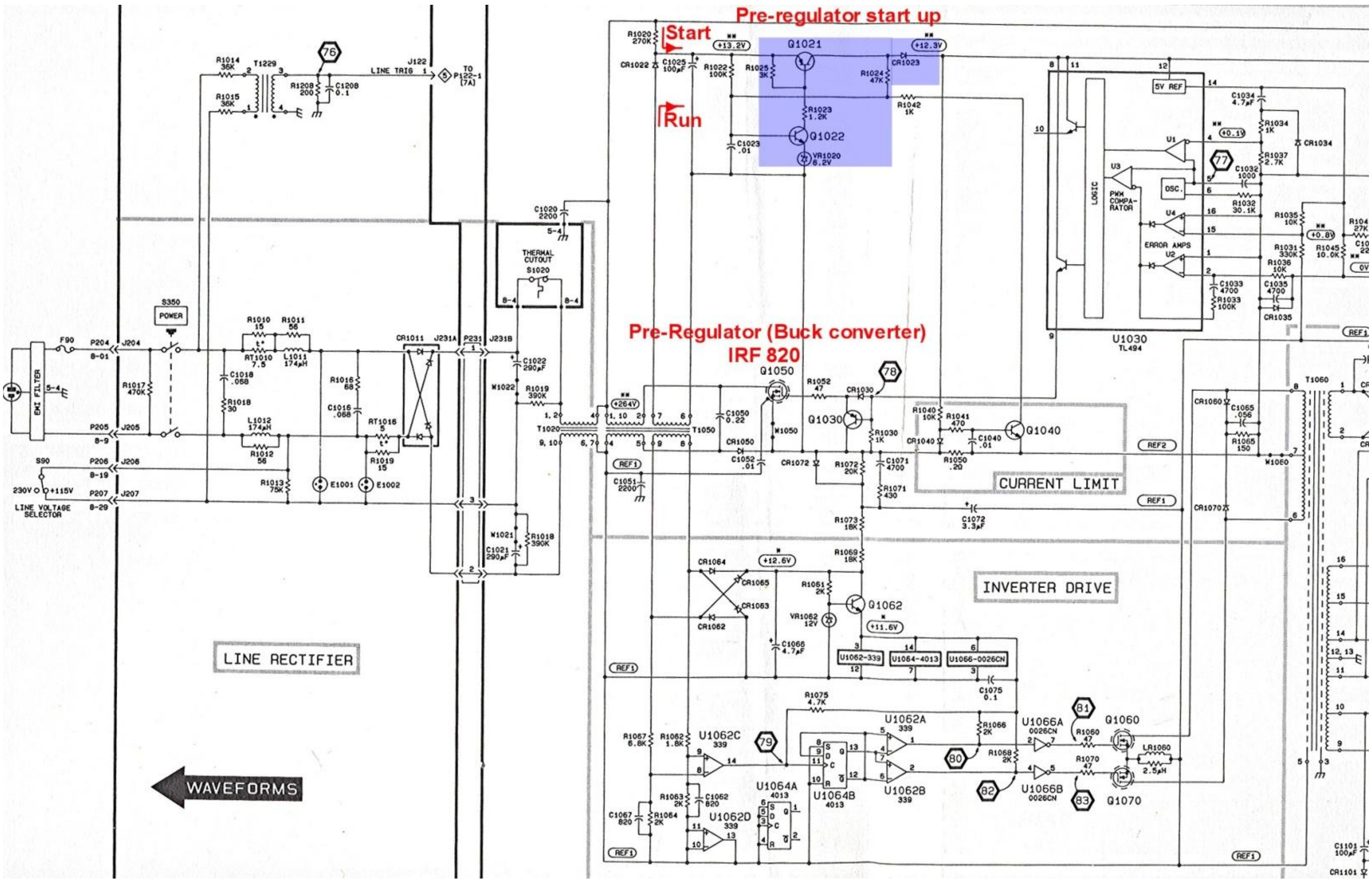
On the right upper corner in the photo on the right above, there two large blue axial capacitors suspended in a black plastic carrier. These are the main filter capacitors on the bridge rectifier outputs. In every 2465B scope I have assessed, these 290uF/200V parts have been perfectly normal with an ESR in the order of 0.04 to 0.06 Ohms, normal capacity & electrical leakage, no electrolyte leakage and not required replacing. Along with other high voltage rated electrolytic capacitors in the 2465B scope these parts appear, for reasons unknown, to have much better longevity than the lower voltage rated electrolytic capacitors. It likely relates to the lower range ripple currents that higher voltage parts experience over the course of their lives.

In terms of capacitor failures in the 2465B, the surface mount electrolytics, if present, fail first on the A5 computer board (physical leakage) followed by physical leakage of the 100uF/25V Green Jacket Nichicon parts in the PSU. Some A5 boards were fitted with Tantalum capacitors, and while these can fail short circuit, they do not usually leak corrosive liquid.

Notice in the photo above, lower right side, the green jacket 100uF/25V rated Nichicon capacitor sitting on its side under the black plastic carrier. This is a capacitor designated C1025 and it is connected with the power supply's initial start up function. This capacitor was involved in the fault, stopping my oldest 1989 vintage 2465B scope from powering up.

As noted, I recently powered the oldest scope of the group. It was totally dead. It had not been used probably for 6 months or a year, since it was last worked on. The 0.068uF X2 Rifa capacitors had failed on the A2A1 board in the past and evolved smoke and been replaced. This is a common problem because the plastic casing cracks, they absorb moisture as they are a metallized paper type. They proceed to physically swell up, opening the cracks further until they become conductive and burn.

The partial PSU schematic is shown below. The *whole area shaded in blue* is the one up for discussion, because it had malfunctioned in my oldest 2465B.



What I discovered was that the incoming line voltage was normal and the two main large filter capacitors had successfully charged up. However, the pre-regulator buck converter based on Q1050 an IRF820 Mosfet and TL494 driver IC was not running.

I connected extension wires onto the Gate and Drain of Q1050, and using a Tek 222ps scope (a scope with isolated inputs) I found that there were no gate drive pulses. The buck converter supplies the pre regulated potential to the primary windings of the main inverter transformer T1060.

The power supply system is moderately elaborate in that the switching drive pulses to Q1050 are modulated in their duty cycle immediately at power up to give a soft start and avoid current surges.

One feature, common to many Line powered switch-mode supplies is that they need an initial way to get started. In this case, current sourced from the main bridge rectifier flows via a 270k resistor R1020 and a start up circuit, to get the Driver IC U1030 running. Once oscillations are established the power for the start-up circuit and U1030 is derived instead from pin 7 & 6 of the Buck converter’s own transformer, T1020.

When the power is initially applied the positive of capacitor C1025, a 100uF/25V part is charged toward the the rectified line voltage via R1020.

The voltage at the base of Q1022 follows at a level determined by by the voltage divider composed of R1022(100k), R1024(47k) and the load provided by the IC U1030, which is likely significantly lower than 47k as it is a SMPS driver IC. This forms about a 32% voltage divider.

When the voltage across C1025 reaches about 21.5v, the base voltage on Q1022 gets to around 0.32 x 21.5 = 6.9v. This overcomes the 6.2V Zener voltage and Q1022’s base-emitter voltage and Q1022 turns on, switching on Q1021 and then both transistors then remain saturated. This effectively places R1024 in parallel with R1022 which reinforces the initial base drive current to Q1022. One job of R1024 appears to be to add some initial Hysteresis to the Switch-On function of Q1022 and Q1021. The initial positive voltage supply to the pre-regulator IC U1030 is then established with supply voltage to it, via CR1023.

If the pre-regulator IC U1030 starts and runs, the capacitor C1025 is re-charged via CR1022 and the buck transformer and it then stays at 13.2V However, after this starting process the pre-regulator IC draws current from the capacitor C1025 and its terminal voltage drops. If the pre-regulator IC and buck converter circuit didn’t run, for any reason, the voltage across CR1025 drains down to about 8V. This causes Q1022 and Q1021 to turn off.

Under a fault condition this “start cycle” would attempt to repeat. In other words the start circuit becomes a relaxation oscillator in the event of a failure. My initial tests showed that this function was not happening either, as there was no activity of any kind in the power up start circuit.

I had now determined from a few simple tests that the start up circuit was not operating. The likely culprit was the 100uF/25V electrolytic capacitor C1025. A quick check on it showed its ESR was a little high compared to a new part.

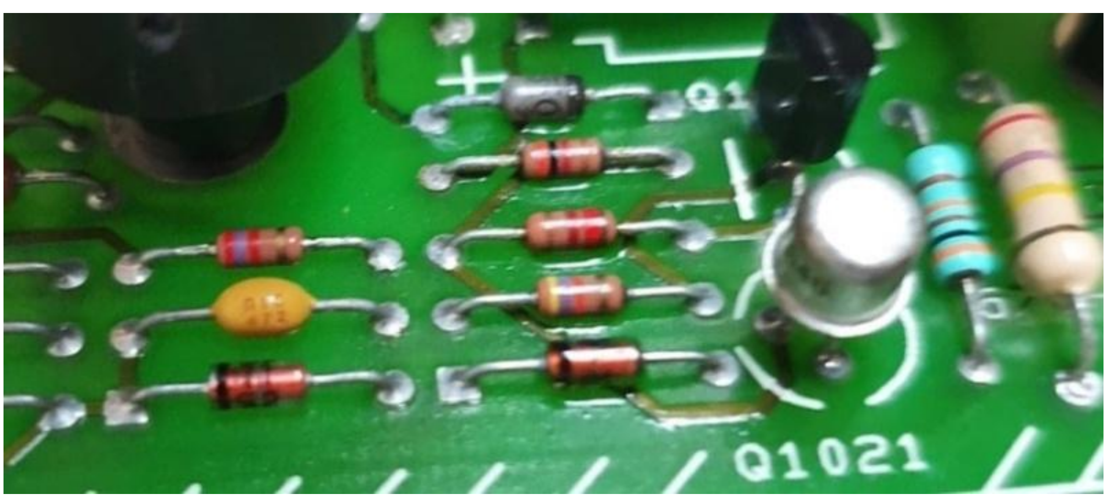
Initially, I had not noticed a couple of telltale signs on the PCB in the area of the start up circuit:

I noticed while manipulating the PCB at a certain angle with a light reflection from the surface, there appeared to be a fluid meniscus under at least four components sitting below C1025: R1025, R1024 and R1023, along with CR1023, VR1020, Q1021 and Q1022.

In essence, the whole area shaded in Blue on the schematic had become a conductive blanket from leaked electrolyte from C1025. But, exactly why did the leaked electrolyte prevent start up?

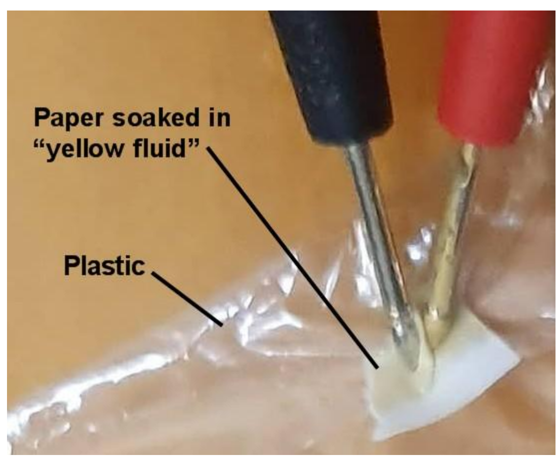
At start up, the voltage at the base of Q1022 is essentially close to the voltage developed across the 47k resistor when the IC is not powered yet. To get Q1022 into conduction its base voltage has to initially exceed around 6.9V. Any resistance added in parallel with the 47k, by way of leaked electrolyte would have to drop the total value of 47k to about 1/3 its normal value to prevent start up. A parallel leakage value of around 25k would be enough. This is likely why the electrolyte disabled the start-up circuit by shunting current around the 47k resistor. Or possibly by shunting current between the base of Q1022 and the circuit common would achieve the same effect. On the other hand, when there is a blanket of conductive material over many components, there are multiple abnormal new circuit pathways.

The photo below shows most of the leaked electrolyte had not evaporated yet. There is corrosion of the solder. Looking closely at the silver Zener diode on the top of the image, its left anode leg is somewhat corroded. This is the hallmark of chemical corrosion caused by leaked electrolyte. Note also on the pcb surface, just near where the anode lead of the silver coloured Zener diode is soldered on the left side, there is a white salty looking deposit on the PCB surface too:



Leakage from the base of the capacitor C1025, sitting above these five parts, was very easy to see after it was removed for inspection. Despite this the capacitor measured normally, at close to 100uF on the Capacitance Meter:

The rubber bung in the base was softened and swollen and electrically conductive with the meter probes. I tore the corner off a piece of A4 paper to use it in a similar manner to blotting paper to extract the fluid from under the components. The fluid was a yellow colour and soaked into nearly the entire square centimetre of paper:



A quick test with the meter probes indicated that the fluid was quite electrically conductive. There may have been some reaction with the Nickel plated Brass probes but very little time for it to occur. The resistance measured in the order of 100k Ohms across a small section of the soaked paper.

A similar experiment with blotting paper and the meter probes found that the electrolyte from the inside the capacitor was far less electrically conductive at around around 1 Meg Ohms on this primitive test with the meter.

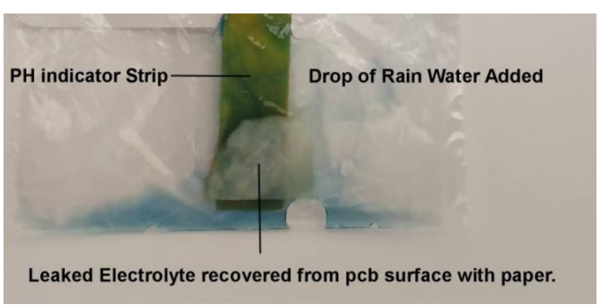
Undisturbed, inside the capacitor, the electrical leakage effect of the electrolyte is also greatly reduced by the fact that one of the foils is covered in Aluminium oxide, which is an insulator.

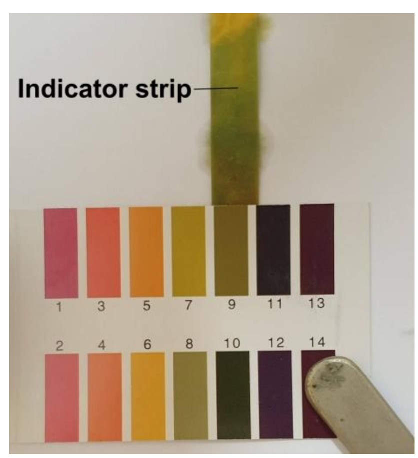
The other 100uF/25V Green Nichicon capacitors I had removed, on testing with 20 volts applied via a 560k resistor for 15 minutes and measuring the voltage drop across the resistor, had a calculated electrical leakage of only 1.5uA, corresponding to a leakage resistance of about 13.3 Meg Ohms. This makes the electrolyte itself, while trapped in the capacitor at least, not very conductive at all. It appeared as though the leaked electrolyte has been involved in a corrosive process with Tin, Lead & Copper on the PCB, with corrosion of those metals.

Further investigations - The Alkaline Shift:

I tested the pH of electrolyte from inside another of the Green 100uF/25v Nichicon capacitor s and it was very close to a pH of 6 to 7. Other new capacitors I have tested, it is in the range of pH of 6 to 7 and sometimes 7 to 8 with some brands, so there is variation in the electrolyte formulations and pH from new.

Luckily, I had saved the paper fragment that I used as blotting paper to scavenge the leaked electrolyte from around the pcb components, it had dried out. As an experiment I put it in a small plastic bag with a pH indicator strip and a drop of rain water. It was quite Alkaline with a pH around the 9 area. I also put a sample of the A4 paper I used in another bag with the indicator strip and a drop of rain water. It was neutral at pH = 7, just to make sure there wasn't any contamination in the paper I had used confounding the test.





Not only is an Alkaline solution corrosive it is much more electrically conductive than a neutral solution and this explained the Ohm meter's resistance readings.

If I had not scavenged the leaked electrolyte with the small section of paper from under the affected component area on the PCB surface and tested it, I don't think I would have discovered this difference between the electrolyte's pH inside the capacitor itself and what happens to it after it leaks out. It sits on the PCB for a while in contact with Lead and Tin in the Solder and Tin and Copper on the component wires.

On investigation, this "Alkaline Shift" is not unexpected because when metals are dissolved by weak acids it ultimately results in an Alkaline solution, the explanation being:

When an acid and a metal react, the metal gives electrons to the H^+ protons to form Hydrogen gas. The oxidised metal (now positively charged) combines with the acid's negatively charged Anions to form a salt. Most soluble salts derived from weak acids form Alkaline solutions. This is because the anions in the salt accept H^+ protons from water. This leaves hydroxide ions OH^- in the water. For example a Lead Borate solution has a pH of 8.6 and a Tin Borate solution a similar value. There was little copper corrosion yet, in this case, but Copper Borate has a pH of about 9.

The pH scale and Electrical Conductivity:

In solutions, anions and cations carry the charges and render the solution electrically conductive.

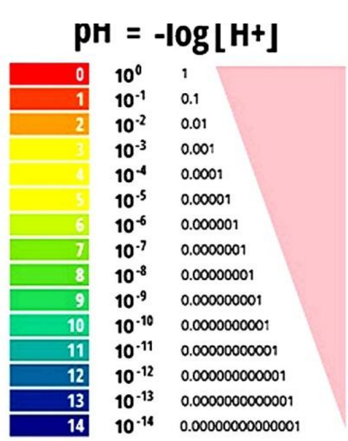
Water dissociates: $H_2O \rightleftharpoons H^+ + OH^-$

The dissociation equilibrium Constant of water Kw (at 25^o C) is the product of the two ionic species:

$$Kw = [H^+][OH^-] = 10^{-14}$$

As the H^+ in the solution increases, the OH^- decreases and visa-versa. The pH scale varies over 0 to 14:

The pH scale is a logarithmic measure of the number of free H^+ protons in a solution, however because of the relationship it is also a measure of the OH^- in solution:



For example a pH 10 solution has about 1000 times more OH^- than a solution of pH 7.

Pure water has the lowest electrical conductivity than either Alkaline or Acidic solutions.

Water with pH of 7 has 10^{-7} moles per litre of dissociated H^+ protons. This works out at one aqueous H^+ proton per 550 million water molecules.

If a solution is more acidic with a lower pH value, it becomes more electrically conductive because of the higher number of aqueous H^+ protons. However, as the solution becomes more Alkaline, there are are less H^+ protons and more hydroxide OH^- anions, again making it more conductive.

Manufacturers of electrolyte solutions generally have tried to keep the pH of the electrolyte as close to neutral as possible, though most are a little acidic. Aging effects inside the capacitors, especially ones where H^+ has reacted with the Aluminium, to evolve Hydrogen gas, result in a shift in the pH toward a higher pH and are more Alkaline. And some electrolyte mixtures are made more alkaline to start with.

Loss of Hydrogen, by way of gas evolution, is obviously very bad for the Capacitor's chemistry and a dome topped capacitor is a sign of it.

Real Life Example of the Alkaline shift - Electrolyte Formulations:

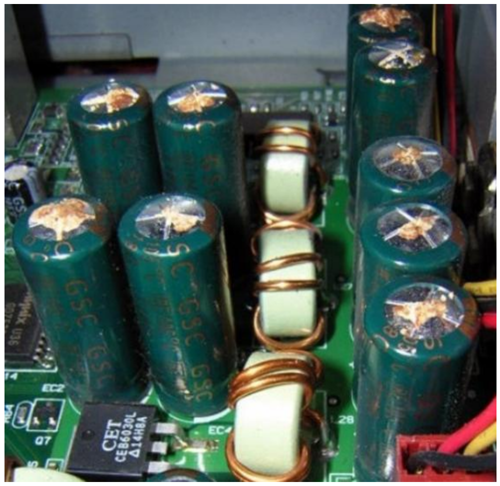
When it comes to the actual formulation of the wet electrolyte for Aluminium Electrolytic Capacitors, it is complex area. It is not just weak acids such as Boric acid, mixed with Ethylene Glycol and water. There are Passivators and Stabilizers added into the mix and most are proprietary (secret) formulas.

Some formulas have even been the subject of industrial espionage and theft. One additive is to prevent the evolution of Hydrogen gas that pressurises and bursts the canister also prevents the solution turning excessively Alkaline inside the capacitor with the development of Hydroxides. Alkaline solutions attack Aluminium, though Aluminium is very resistant to weak acids.

There was an episode of the "Capacitor Plague" around 25 years ago. A Scientist stole a proprietary electrolyte formula from the Rubycon Corporation in Japan and took it to China. But it was incomplete. The formula ended up later in Taiwan made capacitors and many were made there, ending up inside many computers and appliances. They pressurised in short order with Hydrogen, doming their tops and blowing electrolyte out of their tops. They had other faulty electrolyte related failures including increased electrical leakage and increased capacitance. Investigators found evidence of Hydrogen gas and hydroxide in the failed capacitors:

https://en.wikipedia.org/wiki/capacitor_plague

A picture of some of the Taiwanese made capacitors affected by the faulty electrolyte:



If electrolyte leaks out of a capacitor, there are four main issues to consider:

1) The electrical effects of the electrolyte on the circuitry.
2) The short and long term damage to components caused by the electrolyte.
3) The short and long term damage to the pcb caused by the electrolyte.
4) The better method to remove the electrolyte and avoid failures later.

Electrical effects on circuits:

In this case the circuitry involved was relatively “high resistance” in that the resistor primarily dependent for raising the base voltage of the transistor Q1022 is a 100k Ohm part and the source resistance charging the capacitor was also a high value at 270k.

The electrical leakage from the electrolyte was enough to stop Q1022 being brought into conduction at power up, likely by shunting current around the 47k resistor R1024. This explained the fault and why the start up circuit was totally disabled.

However, in low resistance circuitry, with resistances of less than 10,000 Ohms, these could have electrolyte leaked all over them and possibly have no apparent fault, unless with enough time and electrolyte contamination, the shunt resistances dropped to lower values. Or unless PCB tracks got eaten through, or a component went open circuit due to corrosion, but these things are late effects of leaked electrolyte.

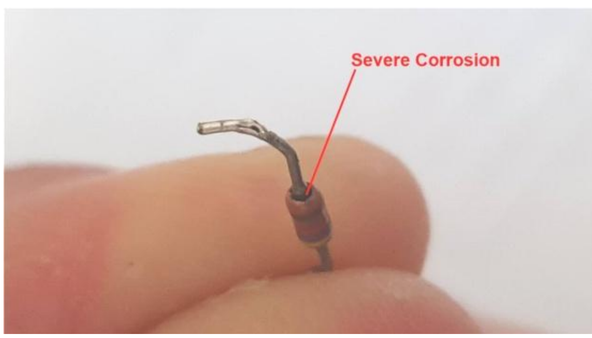
In many ways the fact this start up circuit failed in the scope, relatively early after the electrolyte leaked, was a blessing because significant corrosion damage was yet to occur. And it must have been relatively recent electrolyte leakage because most of it was still wet.

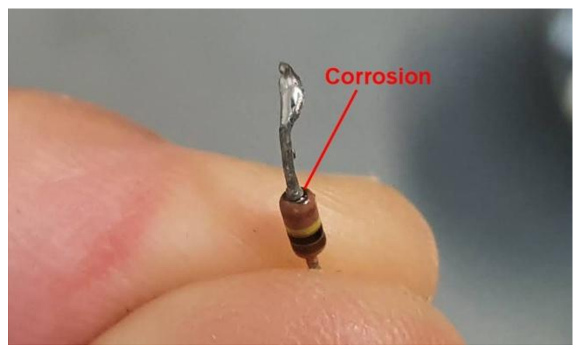
The short and long term damage to components must be considered in a cleanup operation:

Where the Tin plated Copper leads enter a resistor's body, which is often made of ceramic with a metalized coating, corrosion can occur. As this continues there is expansion of the oxides and metal salts in physical volume. This can result in the component failing at a later date. In extreme cases the expansion can crack the entire resistor or a component body, splitting the film and resulting in the resistors going open circuit.

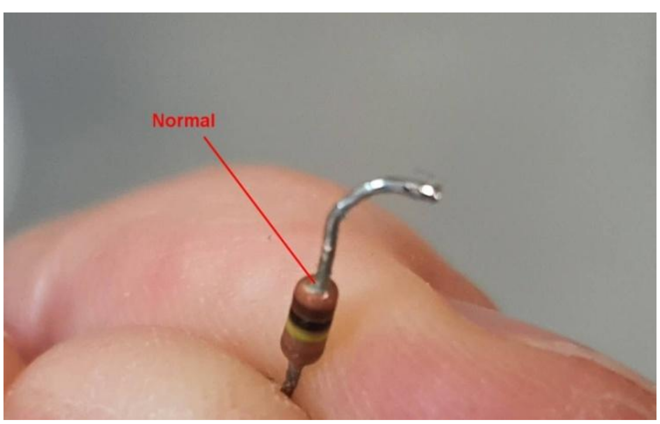
In addition, it was noted in the article on the repair of the 2465B's A5 pcb (link above), that the electrolyte leaked from surface mount electrolytic capacitors also eats through the conductive films on surface mount resistors, rendering them open circuit.

The photo below shows how the corrosion had already entered the ends of the resistor bodies in the 2465B where the wire lead was inserted. Although the 3k, 1.2k and 47k resistors tested ok, I replaced them for this reason. Also the 100k resistor had one leg affected





I also replaced both diodes, the Zener with a 1N4735A and the plain diode with a 1N4148. A photo of the other side of the 100k resistor where the electrolyte had not made contact is shown below left. The photo lower right shows the area cleaned up and repaired:



Short and long term PCB damage:

The PCB is an entirely different problem once contaminated with electrolyte.

The electrolyte, even though not a metal or a semiconductor, is electrically conductive because the charges are carried by Ions, not by electrons. If the ion content increases in the solution, there are more charge carriers and it is more conductive. As previously noted the pH of the electrolyte moves to a very Alkaline value after corrosive effects have occurred and contaminated it.

Unfortunately, the PCB's green conformal coating is not a total barrier to contaminated electrolyte and its corrosive effects. This is evidenced by the coating breaking down after a period of exposure to the electrolyte and the Copper under it beginning to corrode. Also, with voltages applied between copper tracks, the corrosion of the Copper is accelerated by electrolysis and fine tracks are readily eaten completely away over time. Likely, if you find tracks that are fully corroded through, the electrolyte leak occurred many months beforehand and the instrument remained powered after that for a considerable time.

After the electrolyte has been in contact with Solder for a while, the solder loses its shiny metallic surface and acquires a grey oxide like coating. The coating is also a thermal insulator and can sometimes make the component difficult to unsolder, unless its surface is scraped down and fresh solder is added.

PCB cleanup methods:

While a PCB can be cleaned with Contact Cleaner on its surface, this does not help the green conformal coating where the electrolyte has absorbed into the full thickness with moisture and ionic species filling microscopic voids in the coating.

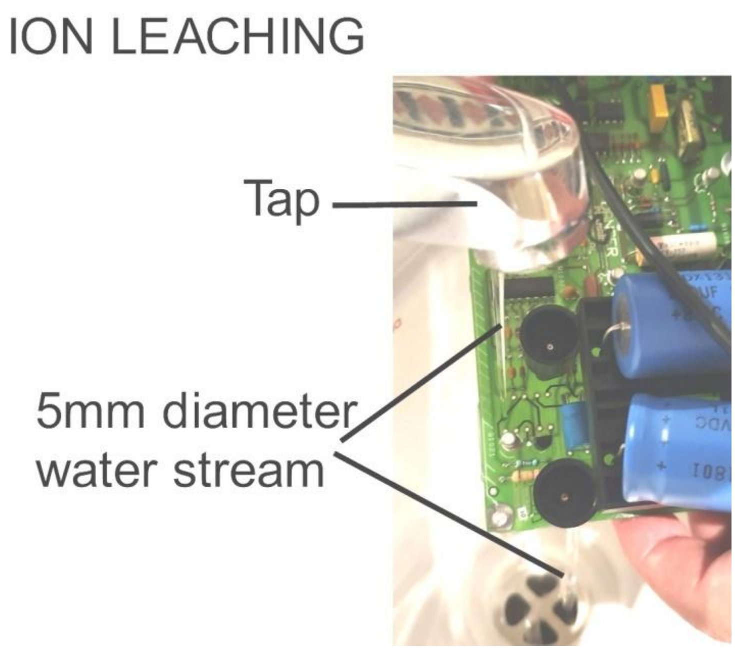
If two adjacent tracks are disconnected from any components and the coating between them has previously been in contact with electrolyte, testing will show electrical leakage between the tracks. *This is evident after the surface of the coating has been thoroughly cleaned with contact cleaner*. While the coating might look physically normal, it is no longer an electrical insulator.

One remedy some have tried is to remove the coating by scraping it off or dissolving it with Methylene Chloride, but this ruins the appearance of the board. Methylene Chloride is toxic and difficult to get in some localities and restricted for public use.

My preferred method to deal with the problem of the contaminated conformal coating is to use a leaching method to remove the electrolyte. But it requires some patience.

The method is called **Ionic Leaching**. It involves letting a thin stream of warm to hot water run over the affected area of the board for at least a half to one hour. The retained ions migrate from the coating into the water and are washed away. If deionized water is available it is superior to Tap Wanter. After that is done, standard contact cleaners (IPA etc) can be used to clean the water off the board.

Ideally the stream of water runs off the nearest corner of the board, with the board held a 45 degree angle. *The whole board is not dunked in water*. Although this can work to leach out ions, there are components than can absorb water and be very difficult to dry out and potentially be damaged. There are people who have put PCB’s in dishwashers to clean them, but it can damage parts especially items such as adjustable capacitors and some transformers and DIP switches and IC sockets etc. Therefore I never do it.



In this case, because the plastic carrier was screwed to the PCB in the area being washed, the nuts had to be released from the carrier, to lift it away from the board surface a little, or water could have become trapped in that area around the stud’s threads.

Rubber Bung/Rubber Base Electrical Leakage:

All of the five 100uF/25V green Nichicon capacitors were removed from the A2A1 board and the three from the A3 board for inspection and testing.

ESR = 0.17 0.28 0.37 0.47 0.3 1.3 0.37 1.3
VL/BL BL BL VL/BL

Date code 8916

100uF 25v VL= visible fluid leakage. BL = bung electrical leakage.

Some of the capacitors had "visible electrolyte leakage" VL. Others had electrical leakage detected with the DVM on Ohms range on their rubber bung, or "bung leakage" BL. This is something not all Technicians are aware of:

If an electrolytic capacitor has leaked electrolyte in the past, it renders the surface of the rubber bung in the capacitor's base electrically conductive and this is easily tested with the DVM on the Ohms range.

All of these capacitors had one thing in common, aside from the date code of 8916, the rubber bung on the base had become soft and a little swollen. The capacitor on the far right in the photo above, with the long leads, is the one removed from the A3 board which leaked electrolyte disabling the scope's power up circuitry.

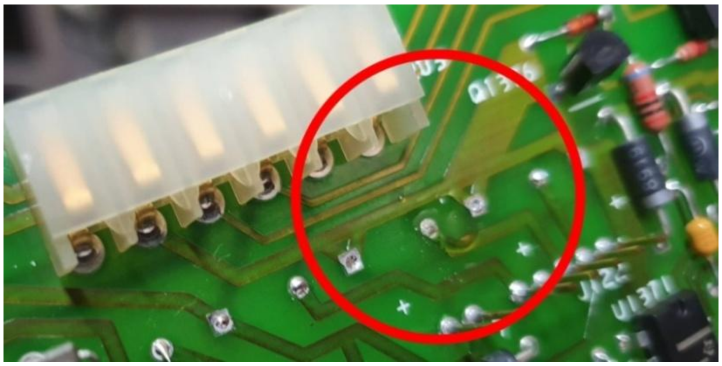
The other two to the left of it were removed from the A3 board also. The five to the left of those were removed from the A2A1 board which was working normally still, even though two of them had leaked electrolyte onto the PCB.

The worse case ESR value printed on the Silicon Chip ESR meter (designed by Bob Parker) for a 100uF/25v capacitor is stated at 0.5 Ohms. The ESR of brand new 100uF/25V capacitors (from my stocks) tested on this meter was 0.14 Ohms or less, depending on the capacitor brand tested.

Of these removed green jacket 100uF/25v Nichicon capacitors, all had higher ESR values than a range of tested new parts with the similar ratings and two of them had ESR's higher than the worse case suggested figure of 0.5 Ohms suggested by the ESR meter's guidelines.

However one part, the 3rd from the left in the photo above, had both VL & BL and had an ESR of 0.37. Therefore the ESR meter's suggested worse case values are only guidelines. If in doubt, compare the measured ESR value to a new part, on the same meter.

The damage on the A2A1 board indicated one capacitor had probably leaking for longer than the one that caused the failure preventing the scope from powering up. There was damage to the board's conformal coating and the electrolyte had started to attack the copper traces. Also where the electrolyte had dried out there were white crystalline deposits:



The Capacitor's Rubber Seal:

Failure or degradation of the rubber seal is one of the reasons why electrolytic capacitors leak. The leakage can also be encouraged by Hydrogen gas evolution, pressurizing the contents and in many cases doming the top of the capacitor. In the case of these particular Nichicon 100uF/25V capacitors all of their tops were perfectly flat. Likely this suggests that when electrolytic capacitors fail due to gas pressurization, they are more likely drying out due to loss of water vapour rather than frank fluid. And in those cases one would expect a significant loss of Capacitance and very high ESR values.

In one example of the drying out issue, in another instrument, a 1000uF capacitor failed and dried out completely. There was no evidence at all of any electrolyte leakage. It had lost nearly all capacitance and went to a very high ESR. I opened it up for inspection and found that it was as dry as parchment paper inside. As an experiment I placed it in a container of deionised water for a few hours. It returned to a normal value of capacitance and a normal ESR. It appears that the seals can partially fail to the extent that water vapour only can escape in some cases, but not frank fluid.

One thing of note about the green Nichicon 100uF/25V capacitors, each of these capacitors read close to 100uF on the capacitance meter and none had excessive electrical leakage. So these two parameters appear less predictive of fluid leakage. The main clues that these particular capacitors were leaking electrolyte is the visible leakage VL and the bung electrical leakage BL and the elevated ESR's compared to a new part.

Since the VL & BL is only easily visible and tested *after removing the capacitor from the PCB*, that really only leaves the ESR as the main "in circuit test" that could give a clue as the whether they are failing and have some early electrolyte leak. Noted also, the softening of the rubber bung was a major associated factor which is also only really possible to detect after the radial capacitor was removed from the PCB.

Another PSU unit from a low hours Tek scope was stripped down for examination of the capacitors. This time the green Nichicon parts had a date code of 8930.

In the case of these parts, the rubber bungs were in good order without softening and they were not electrically conductive, meaning that it was unlikely hay had leaked electrolyte in the past. Their ESR's were a little above the normal range compared to new parts tested (but within the meter guidelines of 0.5 Ohms maximum) and their capacitance was normal on the meter and there was no significant electrical leakage. Testing indicated they were probably ok. Likely, in the next 5 years or so, they will also leak and damage components and the PCB, so I elected to replace these ones. Although, they all had an ESR above the 0.14 Ohm value of my unused stock capacitors.

ESR's ranged from 0.19 - 0.25 Ohms

8930 Date Code. Low Hours Scope

No VL or BL detected

Clearly, apart from the date of manufacture being a factor, the amount of running time is the other main factor leading to some point where the capacitor spills its electrolyte.

Indicators of electrolyte leakage with the capacitor still on the PCB:

1) Visible electrolyte around the capacitor and corrosion of tracks and adjacent components. Loss of a metallic shine on soldered connections.
2) In circuit ESR testing; ESR elevated above the normal range for similar new parts.
3) If a capacitor of exactly the same type and similar date code has leaked elsewhere in the instrument. This elevates the suspicion considerably.
4) Long running hours of the instrument also raises more suspicion.

Indicators of electrolyte leakage when removed for testing & inspection:

1) Damage to the conformal coating and tracks directly under the capacitor.
2) Visible fluid leakage on capacitor's rubber bung (VL).
3) Electrical leakage on the rubber bung (BL).
4) Softening or disintegration of the rubber bung.

Less reliable indicators of leaked electrolyte:

1) Capacitor's uF value, it is often normal.
2) Capacitor's electrical leakage, normal in most cases.
3) Capacitor has a dome shaped top indicating high internal pressure; less likely frank fluid leakage which decompresses the capacitor. And dome toped capacitors are associated with loss of capacitance and high ESR's.

Other electrolytic capacitors in the 2465B:

Other capacitors on the A3 board also should be replaced. These capacitors are interesting in that the manufacturers had attempted to "Leak Proof" them by gluing resin over the rubber bung. This appeared to have worked, except in one case some electrolyte had passed through the bung and around the sides of the leads as they exited through the section of resin. Again the ESR was a little on the high side compared to new parts. The Red-Brown coloured resin was removed from the capacitor on the right, to inspect the rubber bung and test its electrolyte.

On the capacitance meter the 250uF 20v part read 330uF, or abut 1.32 times its marked value. And the 180uF was also about 1.45 times its marked value. The one opened for pH testing had an Alkaline electrolyte with a pH of 8. Interestingly and as noted above, with the Capacitor Plague problem, an increase in capacitance can be a maker of increased hydroxides in the capacitor. I performed an an electrical leakage test on one of the 250uF/20v parts and found that its leakage current was low, at less than 2uA with 20V applied after ½ an hour which is acceptable. However for a new part the leakage current tested at 0.2uA, an order of magnitude lower. Most likely though, unlike the Japanese capacitors which started out with a mildly Acidic electrolyte, this brand started out with a mildly Alkaline electrolyte.

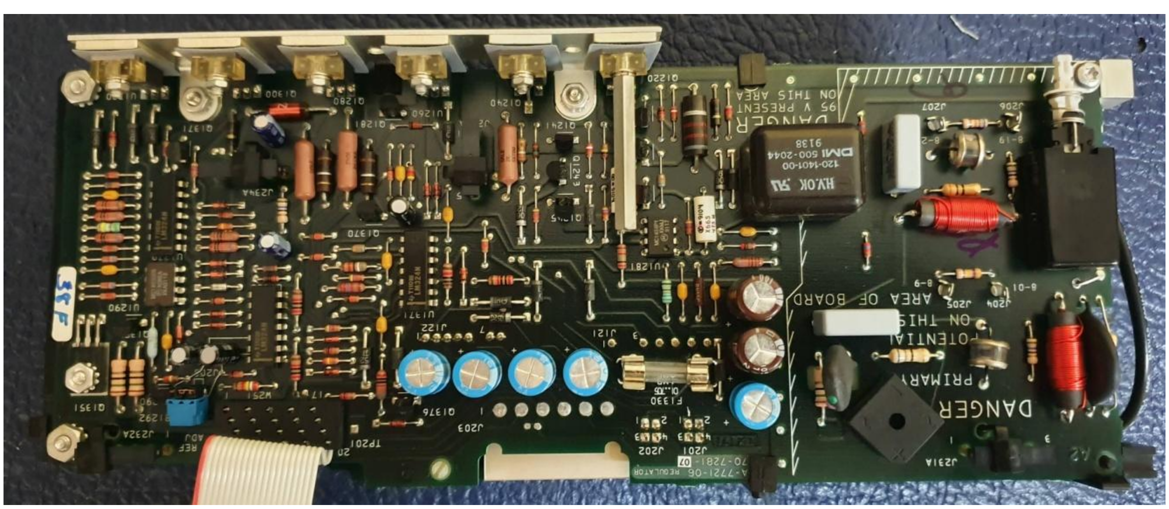
Rather than buying different values I decided it would be reasonable to replace all of these with 330uF/50V 125 Deg C new Nichicon BT series parts. These have an ESR of 0.02 Ohms.

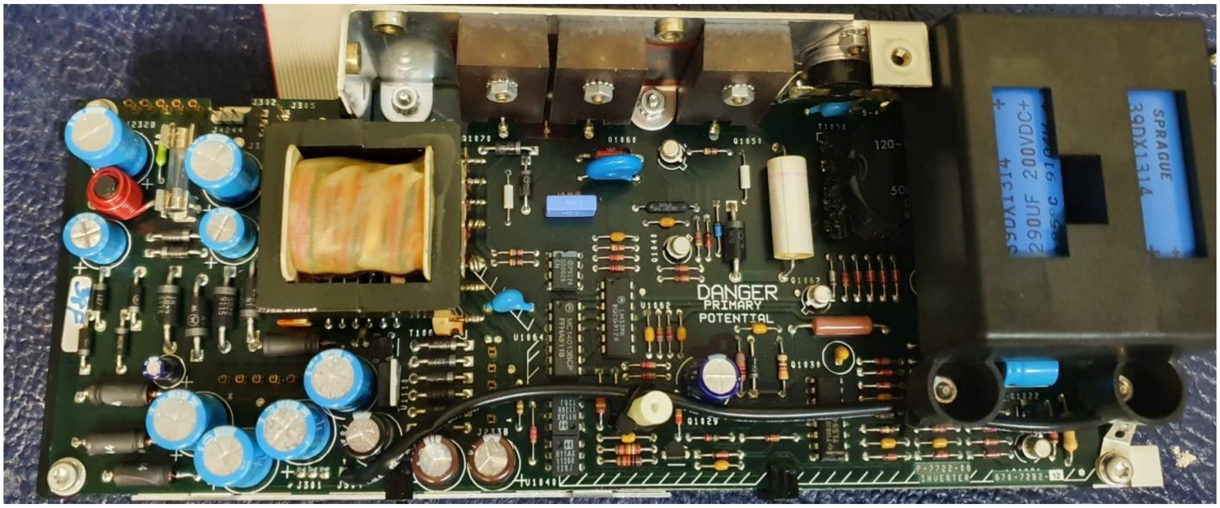
The better electrolytic capacitors to replace the failing ones in the 2465B ?

By far and away my preference is the Nichicon BT series which are very long life 125 Deg C rated types, essentially similar to mil-spec rated parts. There are now very many capacitor choices on the market but after looking at the specifications for many, I am satisfied these are the better part. They can be recognized by their pale blue jackets. The original 100uF/25V parts are better replaced with the 100uF/50V parts, as Tek did in their later model 2465B scopes:

Nichicon BT series 125 DegC

The photo's below show the boards recapped with the New Nichicon 330uF/50V capacitors and the 100uF/50V parts and the replacement Y capacitors using ceramic parts:





Should any electrolytic caps be left unchanged on the A2A1 or A3 boards at this point in time?

There are a few 10uF high voltage electrolytic capacitors on these boards. The higher voltage rated parts seem less likely to fail and leak electrolyte. This may relate to lower ripple currents in the higher voltage applications and the resulting lower thermal dissipation which capacitors have due to their ESR.

The main filter caps in these scopes never appear to have any issues in the four scopes I own. For now I have left these ones in place for observation. Also there are some small electrolytic capacitors elsewhere in the PSU, however these are not surface mount types. They are elevated a little off the PCB on their leads and are easy to inspect and not prone to physical leaking or other failure modes, yet. To inspect these, apart from ESR testing, look closely at the solder on the pad. If electrolyte has run down the lead wire in the past, the solder on the pad will turn a dark grey and lose its metallic shine.

One conclusion that has resulted from the investigation of these Tek scope PSU's electrolytic capacitors, is that when interpreting measured ESR values of aged electrolytic capacitors, rather than using a worse case ESR value guideline suggested by a meter's maker, is to simply check a range of new capacitors of the same uF and voltage rating and use that as the guide as to how deteriorated the aged capacitors might be.

The X2 and Y Safety Capacitor Dilemma:

The 35+ year old Rifa Capacitors should always be replaced. This is because their outer plastic casings crack. They absorb moisture and swell up widening the cracks. The positive feedback effect continues. Eventually the X2 capacitors become electrically conductive, draw current heat up and burn up, evolving copious smoke and making a mess on the PCB well.

The internet is awash with stories about smoking Rifa X2 capacitors. The thing is, when they were new, they were good performers. 30 years down the line though, trouble can start. It may simply be that they were not designed for a longer service of duty. This is similar in many respects to the Electrolytic Capacitor itself, which might be better thought of as a "disposable" part. So it pays not to judge the Rifa parts too harshly. All of my scopes had previously had the two 0.068uF Rifa X2 capacitors in the Line Voltage input area on the A2A1 board replaced in the past. It is better to move away from a metallized paper film product and use a plastic film X2 rated parts. I fitted Wima MKP (polypropylene film) or other plastic film 0.1uF types to replace the vintage 0.068uF Rifa metallized paper types. However the original Y parts are equally problematic.

There are three other Rifa capacitors on the A3 board that now have surface cracking and swelling in all of my 2465B scopes. Two are 2200pF Y capacitors C1020 and C1051. The usage in the 2465B is to bypass both the positive and negative outputs of the bridge rectifier to ground. The customary use is to bypass the Phase and Neutral incoming AC Line voltage to the chassis ground, however the application in the 2465B still relies on them not shorting out.

There is also a 0.01uF capacitor C1052 that couples the negative side of the bridge rectifier output to an electrostatic screen behind the power switching Mosfets on the A3 board.

Looking at the photo below, it is easy to see the horizontal cracks in the bodies of the two 2200pF capacitors on the right. The 0.01uF capacitor's body is starting to swell up on the left:

Y Capacitors to be replaced:

0.01uF 2200pF 2200pF

Generally X2 capacitors are designed for applications directly across the Line Power feed. On the other hand, Y capacitors are designed to connect from the Phase & Neutral lines to the instrument's body or earth. Both types are to aid in the suppression of high frequency interference either entering or exiting the instrument via line power wiring. Often they are combined with inductors to assist the filtering effects.

Long before the Rifa style Metallized paper film "safety capacitors" were invented many manufacturers, for the application of a Y capacitor, used waxed paper types, oil filled types or ceramic types. They got around the reliability issues and mitigated the risk of failure by using capacitors with a substantially higher voltage rating than was apparently required and seldom had any troubles. Some products were encased in metal housing which mitigated the fire risk.

The Y capacitor must be able to support sustained voltages of typically over 1kV. Some manufacturers specify a 4kV DC rating for a Y capacitor which gives a wider safety margin. The reason this is required is that on occasions high voltage transients can ride on the line power voltage. Lightening strikes to power distribution systems are not helpful.

- **Y1: Rated up to 500 VAC with a peak test voltage of 8 kV**
- **Y2: Rated 150 to 300 VAC with a peak test voltage of 5 kV**
- **Y3: Rated to 250 VAC with no peak test voltage specified**
- **Y4: Rated to 150 VAC with a peak test voltage of 2.5 kV**

Failure in the application can be made less likely, when the Y capacitor has 5kV capable insulation. Also Tek added some Gas Discharge voltage arrestors in the line power input circuitry. These also help. They act as a negative resistance and a voltage clamp once they activate.

In any event, the X2 and Y capacitors in the 2465B'a scope's power supply should be replaced now and they need to be suitably rated X and Y parts for the task and for reliability.

Ceramic capacitors generally don't burn very well, except for their outer coating and they are a minimal fuel source compared to a claimed fire retardant plastic part. I prefer them for this reason. Y ceramic capacitors generally have a flame proof coating. And Y parts are designed to fail open circuit. (X2 capacitors frequently fail short circuit or to a low resistance which is why they burn up).

If a Y capacitor did fail short circuit it could apply Phase to the instruments body. Likely that would blow the line fuse or trip the dwelling's RCD. However, if the instrument's Earth connection had broken, or somebody had disconnected the instrument's Earth, it could be very dangerous, especially if the RCD was not present on the dwelling's fuse box or was defective.

Unfortunately, there is a history of people disconnecting an Oscilloscope's Earth connection to gain some Earth isolation for testing Hot Chassis radios & TV's, or the Line voltage side of switch-mode power supplies. For the above reasons, it is a very bad idea to disconnect the Earth on any Line powered instrument, or any kind of Line powered apparatus, which by design originally had an Earth connection to its chassis. In conjunction with certain other failures and combinations of circumstances, it can be lethal.

Fortunately, in the 2465B scope, the line input is protected by fusing prior to the PCB's Y and X2 capacitors, which in some appliances is not always the case. Tek were also clever with the X2 capacitors, in that not only were they placed after the fuse, but they added small low Ohmic value resistors in series with them. If the capacitor shorts the high current vaporises the resistor if the fuse does not blow. This happened in one of my 2465B scopes when the X2 capacitor shorted to a low resistance.

Tek relied on a Japanese pre-made metal cased Commercial Integral Line Power Filter as part of the panel mount IEC Connector, prior to the fuse. You can generally trust the X and Y capacitors inside that unit, being sealed in a metal enclosure, there is no risk of smoke or fire.

In summary my preference for replacing the X2 capacitor is to use Wima X2 rated film parts, and for the Y capacitors to use Y2 rated (labelled) *ceramic types* which have similar proportions to 3kV to 5kV rated ceramic parts:

2200 pF Y

Capacitor :

0.01uF Y

Capacitor :

NOTE: It is more than possible, in this day and age, where many parts get re-labelled and substituted, that some ceramic parts with Y labels could be "fakes" to the extent that they are merely high voltage (5kV) rated standard ceramic capacitor parts. Or some sellers might offer standard high voltage ceramic parts, calling them "safety Capacitors" but the markings on the capacitor do not match or have the safety markings.

Likely, if this was the case, it makes little difference with the failure rate. Probably the practical reality is that the only way to be 100% sure that your ceramic 2200pF Y capacitors won't let you down would be to use 10kV or 15kV rated ceramic parts where the insulation was nearly an order of magnitude better than the minium required for the task.

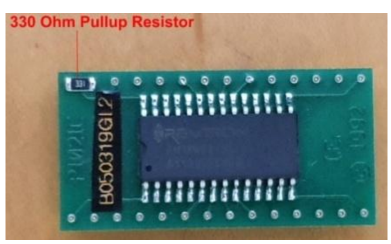
Speed at which the power supply rails collapse at scope turn off and the implications for data storage:

Clearly when the PSU's electrolytic capacitors are in good order with a normal to low ESR's and normal uF capacity, this will determine the speed that most of the voltage rails collapse toward zero at the moment the scope's line power is turned off.

The 2465B uses the Dallas DS1225 battery backed up non-volatile SRAM with an internal Lithium battery. This IC stores the scope's calibration data and other data such as the scope's panel control settings. The DS1225 is characterised by having a unique control IC incorporated into its package, the DS1210, or the DS1218 in later versions of this IC.

When the 5v power rail collapses below a specific level, this chip disables the SRAM and prevents any writes to the IC that could corrupt its contents. It works extremely well, in that any attempts at rapid power cycling the 2465B, I have been unable to corrupt the SRAM's contents in any way.

In previous articles, I had replaced the DS1225 with Ramtron FM16w08 FRAM. This worked very well and many people did this later with very little trouble. However, I did notice that power cycling could occasionally alter the FRAM contents. Fortunately not the calibration constants held there as those addresses are not active at the time of power cycling, but the memory of the last panel control settings are. In one case I was able to ameliorate it with a 330R tie resistor added from the /WE line to +5V:



As the power supply capacitors age and the supply voltages collapse more rapidly at power down, it could corrupt the FRAM contents and if that happened this could also be an indicator to get on and inspect the power supply's electrolytic capacitors.In another article noted above, I found a mechanical solution to the dilemma of the DS1225 with the expired internal battery. This way the original DS1225 can be retained and immortalized.

Summary:

Electrolytic Capacitors have a definite lifespan. The life that can be obtained is determined by multiple factors. It is somewhat analogous to the Nature versus Nurture argument.

One main factor is the construction quality of the capacitor in the first instance. A sophisticated and complex and stable electrolyte mixture helps. The example of the “Capacitor Plague” proved this. As does the physical construction and material of the rubber seal and the purity of the aluminium likely plays a role. The Manufacturer’s temperature rating of the capacitor is a good guide because in general, higher temperature rated parts last longer.

Then there is the electrical and thermal environment the capacitor finds itself living in. High temperatures shorten the life. Placing capacitors in areas too near heat-sinks or with poor ventilation will shorten their life. Circuits with high ripple current will too, because, in conjunction with the capacitor’s ESR, this generates heat inside the capacitor. As capacitors age, in some cases, there can be a general shift to Alkalinity of the electrolyte and increased electrical leakage and even increased capacitance in some cases. Yet, other failure modes consist of drying out, loss of capacitance and elevated ESR values without frank electrolyte spillage.

Unfortunately it is not just the electrolytic capacitor to worry about, because when they leak electrolyte it undergoes a significant Alkaline transformation by reacting with Tin and Solder and Copper on the PCB. It then increases its electrical conductivity, resulting in circuitry malfunctions. In addition it corrodes copper tracks, resistors and other components and electrolysis accelerates this process while the instrument is powered. These features make electrolyte leakage the most problematic and feared feature of the electrolytic capacitor’s multiple failure modes.

To deal with the electrolyte leakage once it has contaminated the PCB and surrounding components is a long cleanup process. If not done well, more troubles will crop up later. Any components that have been in contact with leaked electrolyte are better replaced if they are inexpensive and not difficult to obtain. I recommend the water leaching method to clean the PCB, rather than removal of the conformal coating. If one type (uF and voltage value with the same/similar date code and same manufacturer) of capacitor on the PCB has leaked electrolyte, it is an indicator to renew all of its brothers & sisters on the board, because they will be on the verge of a similar failure.

****