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Those troublesome capacitors, Pt.2

Some vintage radio receivers are far more tolerant of leaky capacitors than others. It all depends on the circuit configuration and the role of each individual capacitor.

LAST MONTH, WE LOOKED at the problems paper capacitors can cause in vintage radios, often because they have become electrically leaky. Paper capacitors are troublesome and require replacement more often than other components, although perhaps not as often as many people believe.

We also looked at the Healing R401E, a vintage radio receiver that can operate successfully with quite leaky capacitors. This month, we take a look at the Healing 505E, which isn't quite so forgiving.

The Healing 505E

As shown in Fig.2, this set is quite different to its older brother. We'll start by considering capacitors C5 and C12. These are screen bypasses and the leakage across C12 should not be less than 20 x R4 (ie, 20 x 100kΩ) which is equivalent to 2MΩ. If C12's resistance is much less than this, the voltage on the 6BA6's screen will be noticeably less than intended and the performance of the set will suffer.

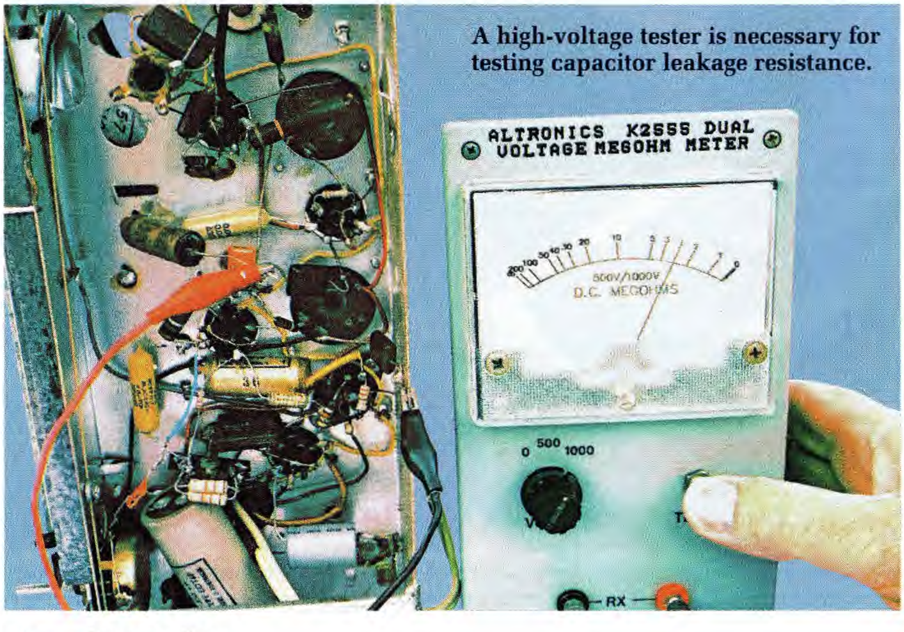
By contrast, C5's leakage can be somewhat greater (less resistance), as R2 is only 22kΩ.

C4 (the AGC bypass) is supplied with AGC voltage via R7 (1MΩ) and both the 6BE6 and 6BA6 valves receive back bias via a combination of R7 and R8. If C4 were to become leaky to any extent, the bias on the valves would be reduced. As a result, they would work harder and the set could become unstable and oscillate.

Basically, if C4 is leaky, the voltage across R7 increases. If the leakage is bad enough, little AGC bias will be applied to the two valves and this will cause distortion and other problems.

In fact, I have always considered the AGC bypass capacitor to be a very important. In this case, it should have a minimum leakage resistance of 20 x (1 + 1)MΩ, or 40MΩ (R7 and R8 are both 1MΩ resistors).

My practice is to replace the AGC capacitor without even testing it and I like it to have a leakage resistance of at least 100MΩ. In fact, I usually replace AGC bypasses with 50V disc ceramic capacitors. They are reliable and easily hidden under other components.



A high-voltage tester is necessary for testing capacitor leakage resistance.

An interesting fault

We now come to capacitor C15 which couples the audio from the detector to the first audio stage (6AV6). The maximum voltage across this capacitor will be no more than about 20V and yet it is rated at 600V! Note also that the grid resistor (R11) for the 6AV6 is a 10MΩ unit.

Why so high you might ask? The answer is that the valve itself develops contact potential bias and the desired bias is obtained by connecting a 10MΩ resistor from grid to earth/cathode. However, such a high resistance means that the leakage across C15 must be around 200MΩ or more, if the valve bias is not to be upset.

Note that most multimeters will be struggling to measure this amount of resistance. This is a very high impedance part of the receiver circuit.

OK, I've said that the voltage across this capacitor is no more than around 20V and that's with a very strong station tuned in. An interesting fault

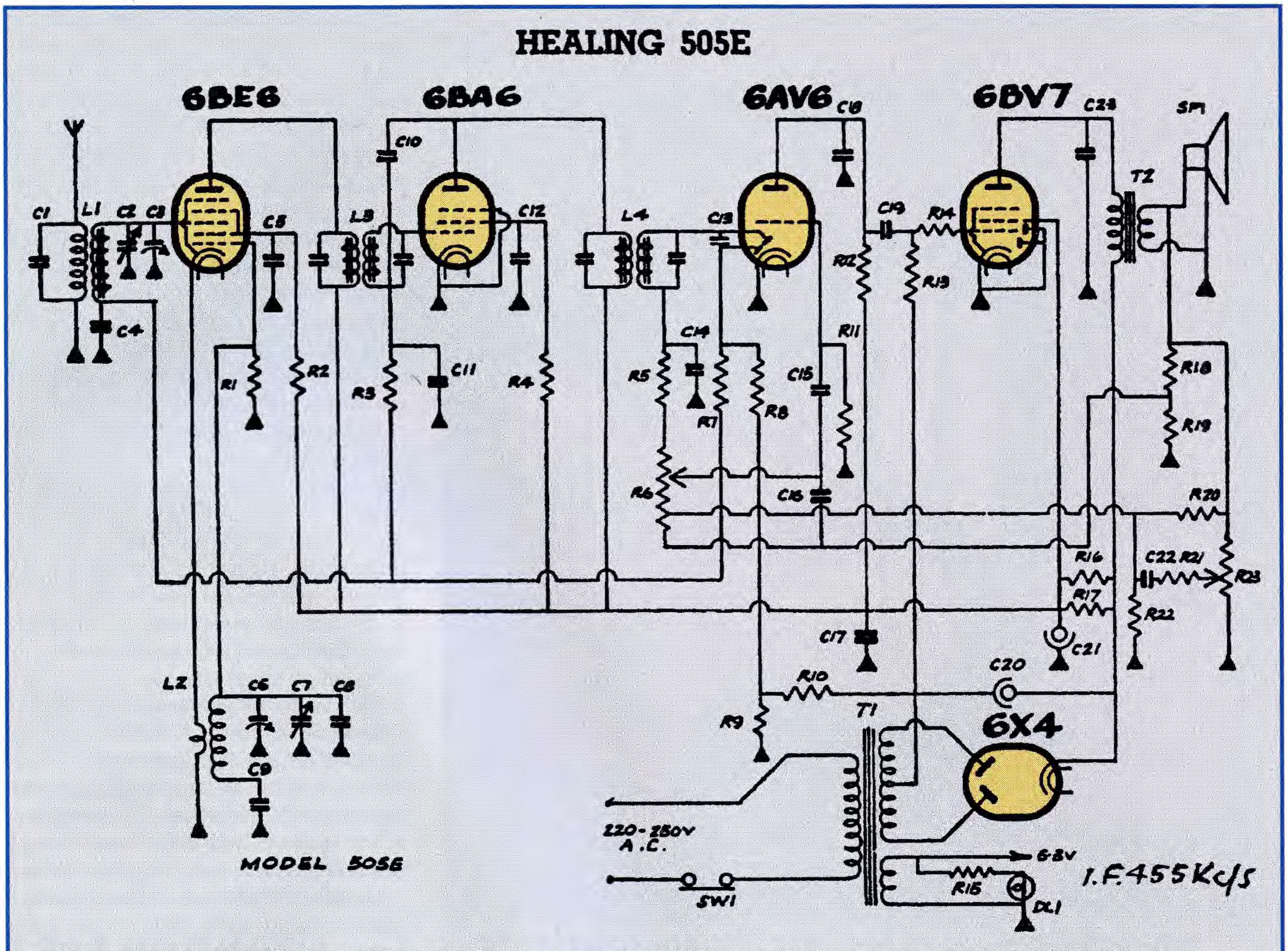


Fig.1: unlike the Healing R401E, the circuit operation of the 505E model is easily upset by leaky capacitors.

shows up when this capacitor is moderately leaky. With a relatively weak station, everything appears to be normal – the volume increases as the volume control is advanced. However, when a strong station is tuned in, the volume decreases as the volume control is advanced and it may even completely disappear as the control is rotated to maximum. Now that is an interesting fault!

Let's see how this occurs. As shown on Fig.1, the volume control (R6) wiper taps off a variable amount of audio and negative voltage relative to earth. This variable negative voltage is applied to the bottom end of C15, while the top end has around -1V on it relative to earth (ie, the contact potential bias).

Now let's assume that the voltage developed at the top of R6 (relative to earth) is -15V and that the wiper is at this position (ie, maximum volume). Further, let's say that the leakage resistance across C15 is R_L. In operation, RL and R11 will act as a voltage divider across R6. As a result, the voltage at the junction of C15 and R11 is [R11/(R_L + R11)] x -15V.

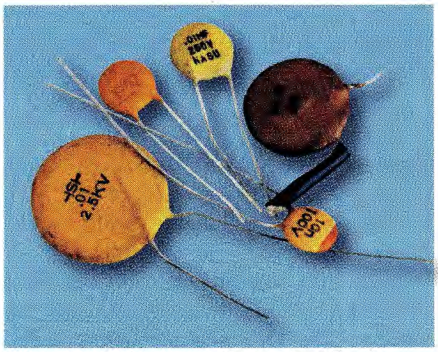
OK, now let's assume that C15's leakage resistance (R_L) is 50MΩ. By plugging this figure into the above equation, we get [10MΩ/(50MΩ + 10MΩ)] x -15V = -2.5V.

If this is added to the existing -1V contact potential bias, it means that there could be as much as -3.5V of bias on the 6AV6. In practice, however, the voltage will be probably be somewhere between -2.5V and -3.5V. But even -2.5V is enough to cut off a 6AV6 in this circuit, resulting in no output on a strong signal at "full" volume!

In fact, even 100MΩ of leakage resistance in C15 will dramatically alter the operating conditions of the 6AV6.

Second audio coupler

Capacitor C19 – the audio coupler between the plate of the 6AV6 and the grid of the following 6BV7 – also needs to have quite low leakage (ie, high resistance). This is necessary for the 6BV7 to work correctly.



Disc ceramic capacitors are ideal for use as AGC bypasses. They are reliable, have very low leakage and easily hidden under other components.

Resistor R13 is 470kΩ, so by my normal rule of thumb, C19 must not

Photo Gallery: General Electric Duette

Manufactured in 1934 by AWA, the "Duette" was a 5-valve reflexed superhet receiver that was electrically equivalent to the AWA Radiolette Model 27. The valve line-up was as follows: 78 RF amplifier, 6A7 frequency changer, 6B7 reflexed IF/audio amplifier/detector/AVC rectifier, 42 audio output and 80 rectifier. Photo: Historical Radio Society of Australia, Inc.

have less than 20 times this resistance to be satisfactory – ie, about 10MΩ. However, in this case, the rule breaks down.

Let's find out why. First, the plate of the 6AV6 is at about +70V and, assuming that C19 has a leakage resistance of 10MΩ, this means that +3.3V will be developed across R13 (this is calculated using the same formula listed above). This means that with -4.5V of bias on the 6BV7's grid and +3.3V R13, the 6BV7 will have around -1.2V of bias.

In reality, it will actually be higher than this, as the valve will draw excessive current through the back bias network. As a result, both the power supply and the 6BV7 will be considerably overloaded and expensive fireworks could easily occur.

So my rule of thumb of allowing a resistance of 20 times the value of any resistor associated with the capacitor is seriously in error in this case - just as it was with the coupling capacitor to the first audio grid. Even if the leakage resistance were 200 times the value of R13, the voltage developed across R13 would still be +0.33V, which is enough to slightly upset a high-gain short grid base valve such as the 6BV7.

As a result, in this location, I expect to see at least 100MΩ of leakage resistance. You can now see why I am rather paranoid about the condition of the audio coupling capacitors.

Other critical capacitors

C18, a 400V mica capacitor, is intended to filter out most of the remaining 455kHz energy in the audio amplifier. Mica capacitors are usually quite reliable but when they do play up, they can be difficult to fault-find.

In this position, the usual effect is a "crackle" in the sound. Tested with a normal multimeter, it may show no leakage resistance and its capacitance may be at the marked value. However, a high-voltage tester will often detect abnormal and varying leakage resistance across the capacitor.

C23 from the plate of the 6BV7 to earth has the normal HT voltage applied across it plus the peak audio voltage. This means that this capacitor needs to be rated much higher than the circuit's HT voltage and about double this voltage is the recommended figure. As a result, a 600V paper capacitor is usually fitted here. If its leakage resistance is relatively low, this capacitor can get quite hot and can go short circuit.

C17 is the RF bypass across the HT line and has the full HT DC voltage applied across it at all times. Theoretically, it can be very leaky and still function OK. However, if a capacitor is too leaky, it will behave as though there is also a resistor inside its case. As a result, it will heat up and this can have a cumulative effect – as it gets hotter, its resistance drops and so it gets even hotter.

This can easily develop into a runaway scenario and the capacitor needs to be replaced "pronto".

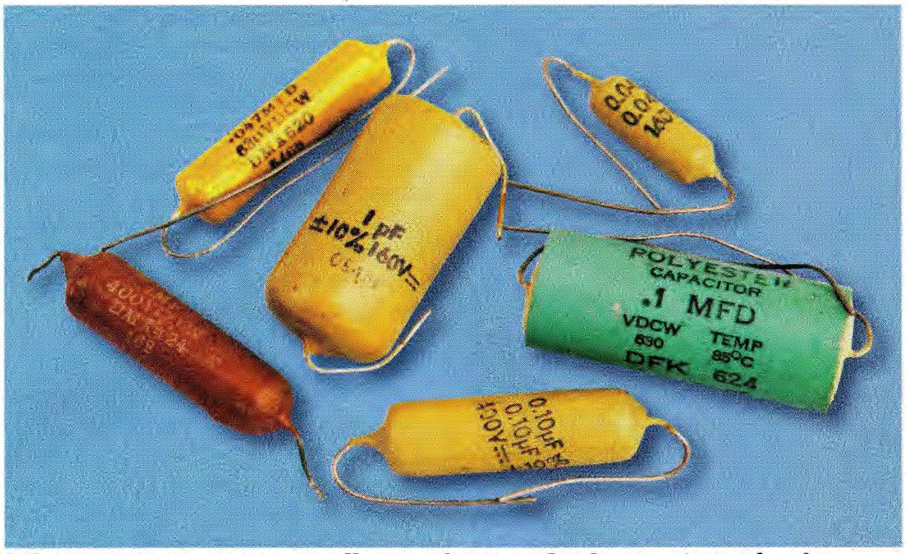
A word of caution is needed here. Before checking whether a capacitor has become warm to the touch, do the following things for your safety:

(1.) Turn the set off and remove the power plug from the power point (if the set is left connected to the power point, 240VAC could still be lurking in the receiver waiting for an unwary finger to touch it!);

(2.) Make sure that the high-tension (HT) voltage has disappeared (check the HT line with your multimeter).

Only then can you can put your "pinkie" on the insulated case of the capacitor to check whether it has become warm or not. A time-honoured technique is worthy of mention here – when probing around the inside of a set, keep one hand in your pocket. This is particularly important when using a test instrument on a live receiver.

Finally, C22 in the tone control circuit can be quite leaky and will



Polyester capacitors come in all sorts of sizes and voltage ratings. They have low leakage (although not as good as polystyrene types), are generally very reliable and can be easily hidden inside the cases of defunct paper capacitors.

have little effect on the operation of the control.

In summary, unlike the older R401E model, the Healing 505E generally cannot tolerate leaky paper capacitors. The audio coupling capacitors in particular are critical and these and a number of others need to be carefully tested. In some cases, it even pays to replace them as a matter of course.

Replacement capacitors

A 1nF (.001µF) capacitor must have a lot less leakage current through it than, say, a 270nF (0.27µF) capacitor. My rule of thumb is that no paper capacitor should have less than 2MΩ leakage resistance, while a 1nF capacitor should have at least 10-20MΩ minimum leakage resistance (as should other similar low-value capacitors). However, it does depend on just where it's going to be used in the circuit.

Some brands of capacitors were more prone to leakage than others. Ducon capacitors in the 1940s, 1950s and early 1960s were notorious for becoming leaky. UCCs were also sometimes leaky but more commonly became intermittent.

By contrast, the older Chanex capacitors seem to be more reliable and some of the "moulded mud" AWAs were OK as well, although many split their cases.

So what caused some brands of capacitors from certain periods to have a bad reputation? Frankly, I don't know, although I do have some thoughts on the matter. Perhaps someone who was employed in that part of the industry could enlighten me.

The Philips polyester capacitors that came onto the market in the early 1960s were a quantum leap forward as a replacement for the paper capacitors. Their reliability and low leakage is well known, although I had a polyester unit unexpectedly blow up just recently. There was smoke everywhere from it and the resistor that also burnt out when it failed (it went off like bunger).

However, that's just something that happens sometimes and polyester capacitors really are very reliable. There is no doubt that valve radios would have carried on for much longer if they had been available much earlier (ie, when the radios were manufactured).

Testing capacitors

There are two test procedures that will usually sort good paper capacitors from the bad ones. A check of the resistance between the two terminals of the capacitor is one such test. However, a normal multimeter will not give a reliable indication of the leakage resistance, as the applied voltage will be no higher than around 9V. Instead, it must be done using a high-voltage tester.

Altronics have such a high-voltage tester as a kit (Cat. K-2555) and the price is quite reasonable. It can test capacitors for leakage at either 500V or 1000V and is invaluable for testing nearly all capacitors other than electrolytics.

A high-voltage test will usually show up any capacitor with a leakage resistance of 200MΩ or less. 200V capacitors can be tested on the 500V range, as they usually have a peak rating well in excess of their normal operating voltage. Similarly, 400V units can be tested at 500V, while 600V (or 630V) capacitors can tested at 1000V.

Heat also has quite an effect on the leakage resistance of a capacitor. Some

A selection of mica capacitors. Mica capacitors are usually quite reliable but when they do play up, they can be difficult to fault-find.

time ago, I salvaged all the paper capacitors from an old valve b&w TV set. To test them, I first heated them in an oven to about 70°C then checked them using a conventional ohmmeter.

Did I get a shock – they had all tested OK when cold but it was an entirely different story after they came out of the oven. I ended up throwing the lot in the bin. By contrast, the polyester capacitors I had salvaged from the same set were quite OK.

Checking in-situ

Checking capacitors in-situ (eg, in an old radio) involves first lifting one end of each capacitor in turn before checking it with the high-voltage tester. They can also be heated with a hair-drier so that they are warm (but not hot) and the checks repeated. You will soon discover whether a capacitor is worth leaving in the set or not.

A selection of polystyrene capacitors made by Ducon. Polystyrene capacitors have extremely low leakage.

A larger-value capacitor acting as (say) an HT RF bypass can be left in the set after passing a leakage test. It can then be reconnected, after which the set can be switched on and the HT voltage checked. If the HT is OK, wait a few minutes, then switch the set off and disconnect it from the mains. Finally, check that the HT rail has disappeared (use a multimeter) before checking the HT bypasses and electrolytic capacitors to see if any are warm. If they are, it signals that the units are too leaky and need replacing.

Why the high voltage?

As mentioned earlier, the Healing 505E uses several high-voltage paper capacitors in relatively low-voltage sections of the circuit. The reason for this is that the high-voltage units had better insulation and therefore less leakage (ie, higher resistance) than low-voltage types. As a result, high-voltage capacitors were used where low leakage was critical to the set's performance.

By the way, I have also found that paper capacitors have less leakage when only a low voltage is applied across them. As the voltage across them increases, so does their leakage.

"Earthy" end

Paper capacitors often had a (black) band at one end of the capacitor. This indicated the end that should go to earth when the capacitor was used as a bypass – or alternatively, the end that should connect to the lower impedance part of the circuit.

Why was that? Well, the band indicated the pigtail lead that was connected to the capacitor's outer foil. This outer foil (when earthed) acts as a shield, thereby reducing RF radiation when the capacitor is used as a bypass or filter.

Summary

(1.) The leakage resistance of a paper capacitor depends on the voltage across it, its voltage rating, its capacitance and its temperature.

(2.) The circuit position dictates how leaky a paper capacitor can be and still be considered satisfactory. Audio coupling capacitors and AGC bypasses, in particular can have very little leakage, with a leakage resistance of around 100MΩ or more being the minimum acceptable resistance. This is to ensure that there is little or no alteration to the operating conditions of the part of the circuit they connect to.

By contrast, bypass capacitors can be quite leaky (a cathode bypass can be down to several kilohms in some cases and still operate satisfactorily). However, I recommend a minimum resistance of around 2MΩ for these capacitors.

(3.) A capacitor's leakage resistance will reduce (ie, the current through it will increase) when used in a set due to internal heating, particularly if the capacitor is relatively leaky. I consider a leakage resistance of at least 1-2MΩ to be the minimum for a large paper capacitor but this should considerably higher for low-value capacitors.

(4.) The circuit design will dictate how leaky the paper capacitor can be in certain location for the receiver to operate normally. Note the comparison between the Healing 505E and the Healing R401E described last month.

(5.) To ensure authenticity, keep at least some non-critical paper capacitors in a set. A good trick is to remove the internals of paper capacitors and fit polyester capacitors (which are physically smaller) inside the cases of the old capacitors.

That's it on the subject of paper capacitors. We'll cover electrolytic, mica and other lesser-known capacitors in a future article a little further down the track. **SC**