CapCoder

A PIC-based capacitive sensor encoder for frequency tuning of amateur radio sets

I ordered a Xiegu G90 HF Transceiver In May 2021 because with its 20 W output power, built-in ATU and very compact size it looked like the perfect travel companion for my amateur radion activities from abroad. However, when it arrived I was very disappointed for just one single reason: *the main tuning control is a primitive and cheapo mechanical rotary encoder with 20 detents !*

The serious radio amateur listens a lot and is very frequency agile, and he typically invests much more time in tuning up and down the bands than in transmitting. Therefore tuning must be effortless and precise and that's not provided by a control that has a static tuning rate of 200 Hz per revolution and must be switched to higher rates and back by repeatedly pushing a button. That's why in my eyes this type of encoder - which will also sooner or later wear out - is totally unsuited and an unacceptable "no-go" for the main tuning control of a radio set.

new application for an old idea

Being a passionate high-speed CW operator, in the late 1990s I had the idea for a sensor-paddle based on the *self capacitance* of the human body. Over the years I developed and built many analog and digital circuits of capacitive sensor-paddles for electronic Morse code keyers which lead to the latest evolutionary step *CapKey+* [1]. And suddenly I realized that its predecessor was ideally suited to serve as the basis for an encoder that has no moving parts and is *touched* instead of rotated.

I modified my original PIC program for that task and the result is *CapCoder*, a *Cap*acitive sensor en*Coder* which needs no adjustment and is self-calibrating, very reliable and sensitive and allows for slow and fast tuning without pushing a button. Please have a close look at the picture on the left: the main tuning knob of the G90 has been replaced by a small black box measuring 2.5 x 2.5 x 1.5 cm with a push-button and red LED. It is attached to the front panel, its two side plates are touch-sensitive and it houses the complete *CapCoder* circuit. On the following video you can see and hear *CapCoder* tuning of my G90 (click on the link to start the video):
http://cq-cq.eu/assets/dj5il_vi002e.mp4

In this article I will show you how I modified my G90 for serious frequency tuning. However, if you really want to modify your G90 (or QCX QRP transceiver kit by QRP Labs, which has the same unsuited type of encoder, or any other radio set) in the same way please be aware that very precise mechanical work and soldering are prerequisite.

Many thanks to Adrian Florescu, YO3HJV, for his valuable help and advice how to disassembe the G90 front-unit and where to get the supply voltage for my *CapCoder*. Upon my request he made a superb video which is published on youtube [2]. Do *not* try to disassemble the G90 front unit without having carefully studied this video !

circuit details

The *CapCoder* circuit is shown in fig. 1, programmed PICs 12F683 are available from the author and the firmware hex-file can be downloaded [3] for personal non-commercial use. The four Schottky diodes BAT41 can be replaced by any similar type.

The controller in the front-unit of the G90 is an STM32F103R (ARM 32-Bit Cortex-M3 CPU), the encoder is connected to Pins 55/56 which are 5V-tolerant I/O ports. These pins are weakly pulled up to the supply voltage and while the original encoder is rotated it shorts these pins to ground in Gray-coded sequence which allows to detect the direction of rotation.

The controller's supply voltage is delivered by an AMS1117 3.3 V LDO regulator, and because the *CapCoder* is powered from the same voltage source no transistor interface is necessary and its encoder outputs A/B can be connected directly to the associated soldering pads for the original encoder on the controller-board.

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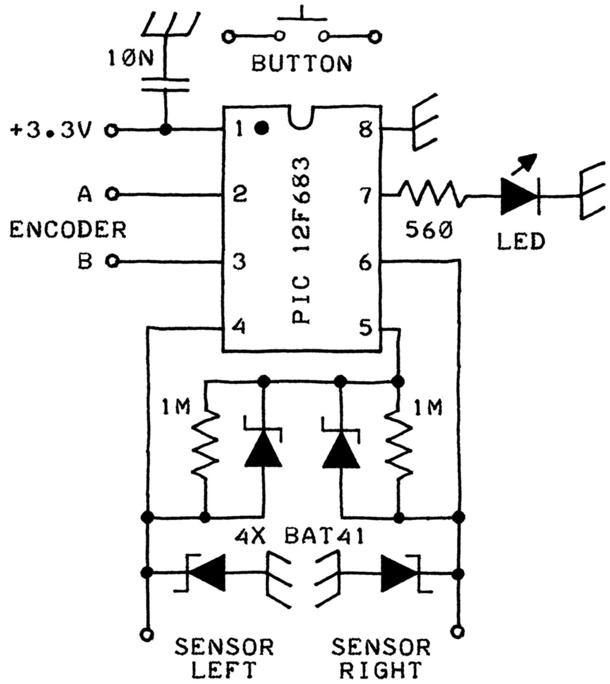

fig. 1 - ***CapCoder*** **schematic diagram.**

construction

Though the *CapCoder* circuit is very simple its construction is quite demanding. Please consider the following description to be just an incentive and suggestion how it can be built and integrated.

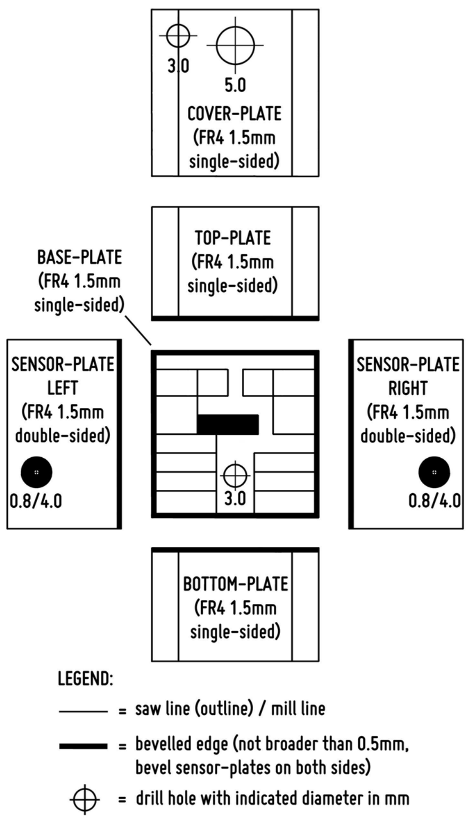

fig. 2 - Parts template.

Caution: the orientation of all components must be carefully checked before any grinding or soldering is done, otherwise a lot of work might be in vain. Very thin solder and a point solder tip must be used.

Step 1:

The parts template in fig. 2 was printed out at 100% scale on a sticker paper, the six parts were cut out leaving a narrow margin around the outlines and then sticked on single- and double-sided epoxy FR4 1.5 mm printed circuit board (PCB) material as indicated.

The holes were drilled with an additional 2 mm hole somewhere within the black rectangular area on the base-plate. *Only the 0.8 mm holes on the two sensor-plates go all the way through, the black circular areas around them are blind holes made by counterboring the 0.8 mm holes with a 4.0 mm drill a bit less than 1.5 mm deep into the 1.5 mm thick plates.*

Then the six parts were sawn out with a jigsaw, going as close as possible to the outlines but making sure that they were still visible. Also the black rectangular hole in the base plate was sawn out. With a sheet of medium grade sandpaper lying on a plane surface all edges were carefully grinded until the outlines were just still barely visible, then the indicated edges were bevelled.

The sticky paper and underlying copper plane were milled off along the lines with a small diameter ballpoint burr and a handy dremel tool. Finally the

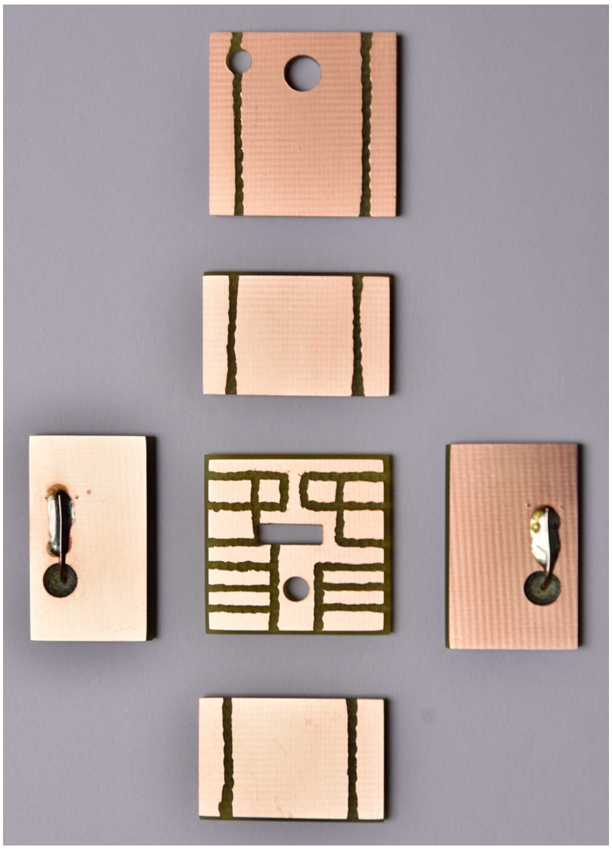

fig. 3 - Prepared PCB parts.

remainders of the sticker paper were peeled off and the copper surfaces thoroughly cleaned with isopropanol and cream cleanser until shiny.

With a center punch and hammer a small dimple was engraved into the un-counterbored side of the 0.8 mm hole on both sensor-plates, a short piece of blank copper wire sticked through the hole, bent over and soldered to the copper plane on the counterbored side. It was also soldered to the other side of the plate by straightening it up, applying a *tiny* portion of fluid solder into the dimple and clipping off the excessive wire. With sandpaper lying on a plane surface the excessive solder was grinded off by moving the plate with soft pressure in circular motion over the sandpaper, taking care not to grind off the copper layer. The prepared parts are shown in fig. 3 which is not-to-scale.

Step 2:

With the copper side up the *base-plate* was pressed onto a piece of double-sided sticky tape attached to a plane surface, a 3 mm brass hex nut was positioned exactly over the 3 mm hole and soldered to the copper layer.

Then the t*wo sensor-plates* and the *bottom-plate* were arranged upright to form a "U" around the three associated sides of the base-plate according to the parts template. The two sensor-plates were soldered to the bottom-plate taking care that the solder does not flow down to the base-plate and at least 2mm from the upper edge of the plates remain free of copper and resin. The "U" assembly is shown on fig. 4, note the blind hole on the inside of the upper (left) sensor-plate and the solder-filled and grinded dimple on the outside of the lower (right) sensor-plate.

fig. 4 - "U" assembly.

Leaving the base-plate together with the "U" assembly on the sticky tape, two sets of 2-pin strips and mating 2-pocket strips were prepared an sticked together. The solder-pins of the pin strips were bent with pliers by about 45° and those of the pocket strips in the other direction by 90°, then these two sets were soldered to the base-plate and two sensor-plates as shown in fig. 5. Again, care must be taken that at least 2mm from the upper edge of the plates remain free of copper and resin, and there should be a small clearance between the pocket strips and the sensor-plates.

fig. 5 - Pin strips and pocket strips are installed.

The edges of the *cover-plate* were regrinded to fit snugly into the "U" assembly, then all parts were removed from the sticky tape. The "U" assembly was detached from the base-plate, laid with the pin strips pointing upwards on a plane surface and soldered to the fully inserted cover-plate at the two corners, the center of the bottom-plate and between the two pin

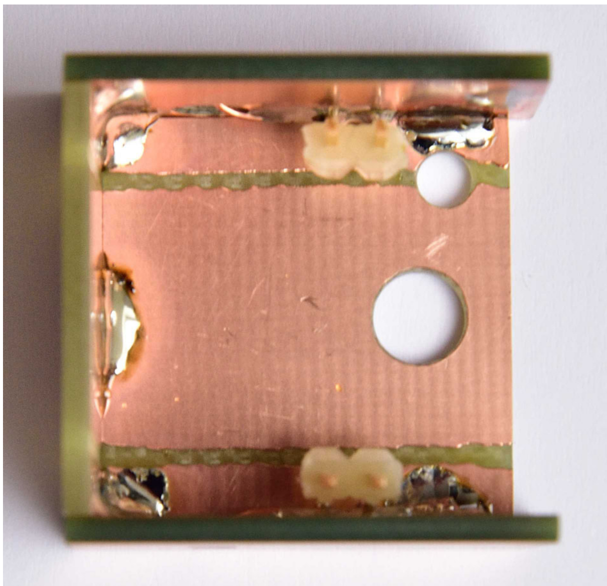

fig. 6 - "U" assembly soldered to the cover-plate.

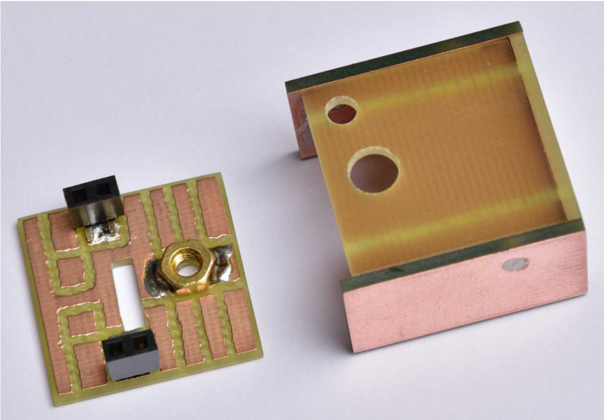

fig. 7 - Base-plate on the left and "U" assembly with cover-plate on the right.

strips and the edge of the cover-plate. The result is shown on figs. 6 and 7.

Step 3:

All circuit components except for the push-button and LED were soldered to the base-plate. Finally the solder-pins of the push-button and LED were trimmed, adjusted and soldered to the base-plate *with the cover assembly attached*, so that they could take up their correct position.

The push-button is a panel-mounted type with 5 mm thread, it also serves to secure the cover assembly on the G90 front plate. If it is shorter than the specimen shown its solder-pins must be extended, it should stand out from the cover-plate just far enough so that its nut can be screwed on.

The completed base assembly is shown in fig. 8. The two 1 MΩ / BAT41 parallel combinations from the PIC pins 4 and 6 to pin 5 and the BAT41 from pin 6 to ground are mounted vertically, note the wire bridges and the brass nut below the IC socket.

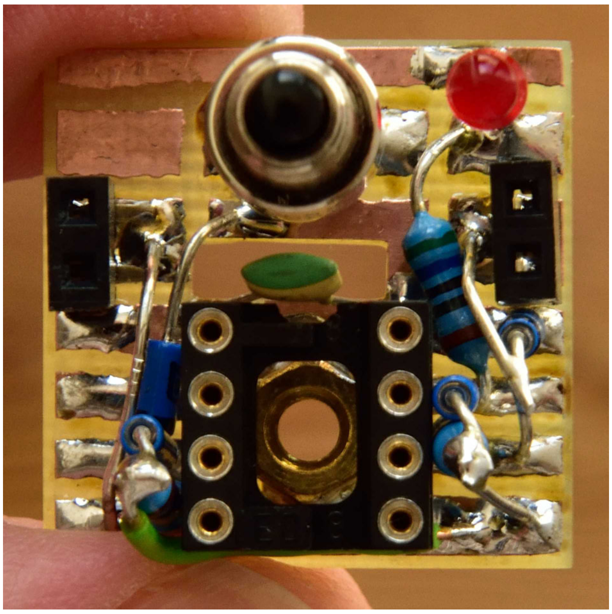

fig. 8 - Base assembly.

The edges of the top-plate were regrinded to fit snugly into the cover assembly standing on a plane surface with its open top-side, then both parts were soldered together. Again, care must be taken that at least 2 mm from the edge of the plates remain free of

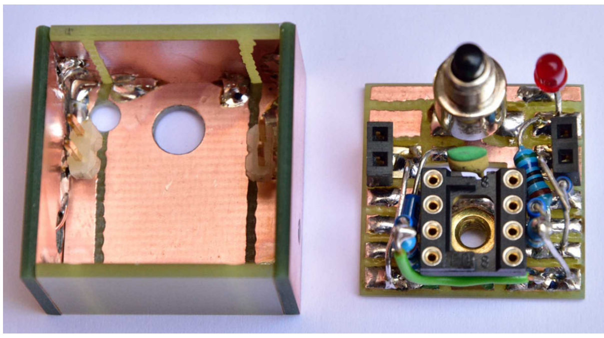

fig. 9 - Cover assembly left and base assembly right.

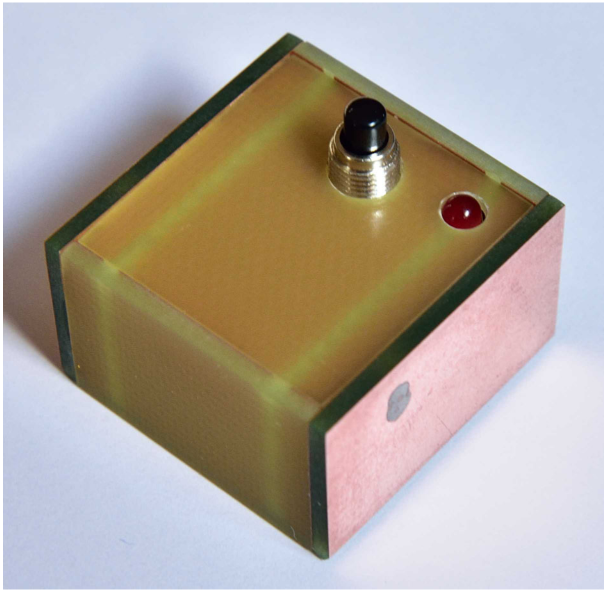

fig. 10 - Base assembly with Cover assembly, front view.

fig. 11 - Base assembly with Cover assembly, rear view.

solder and resin. Finally the edges of the base assembly were regrinded to fit snugly into the cover assembly. Fig. 9 shows the completed cover assembly on the left and the base assembly on the right, figs. 10 and 11 show the base assembly with attached cover assembly.

The following steps describe the integration of the *CapCoder* unit into the G90 ...

Step 4:

The G90 front unit was detached and disassembled, then with a round file the rectangular hole for the original encoder in the console was extended centered to about 9 mm below its edge and a 3 mm hole was drilled through the front plate centered 4 mm below the edge of the 9 mm circular hole. The result it shown in fig. 12 with the console at top and the front plate below.

fig. 12 - Modified G90 console (top) and front plate (bottom).

Step 5:

The original encoder was desoldered from the controller board and discarded. From color-coded ribbon cable 20 cm of *red* and 5 cm of *black*, *grey*, *white* and *yellow* (2 pieces) wire were separated. The *red* wire was soldered to the center pin of the 3.3 V LDO regulator and routed to the other side of the controller board through one encoder mounting hole (fig. 13) . Then it was shortened so that it stood out 5 cm from the board and its end was stripped and tinned.

The other wires were stripped and tinned at both ends and soldered on the front side to the encoder pads as follows: two *yellow* to the two pads at the top and *grey* to the left, *black* to the middle, *white* to the right pad at the bottom (fig. 14).

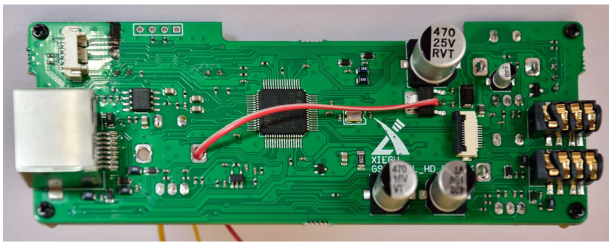

fig. 13 - Red wire soldered to the 3.3 V regulator and routed through encoder mounting hole.

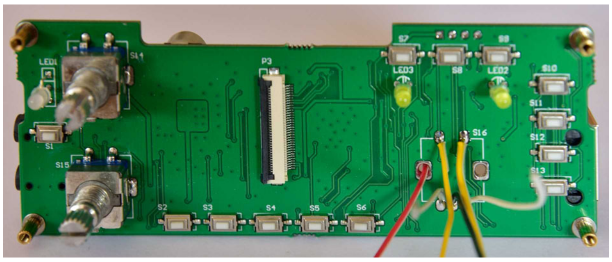

fig. 14 - Red wire standing out 5 cm from the board and yellow, black, grey and white wires soldered to the encoder pads.

Step 6:

The strip below the rectangular hole for the encoder on the white rubber keypad was removed with a scalpel and the keypad was reassembled on the front of the controller board together with the display (fig. 15). Then this assembly was carefully fitted from the back into the console with the wires routed through the extended rectangular hole (fig. 16).

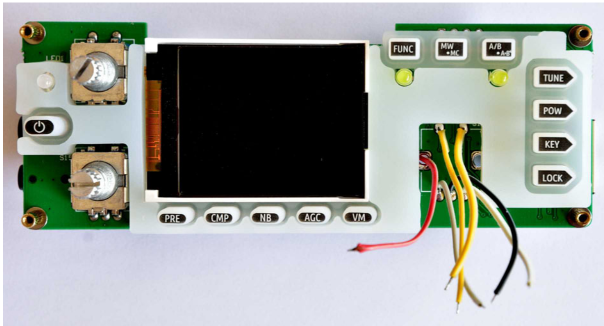

fig. 15 - Modified keypad and display reassembled on the controller board.

fig. 16 - Controller assembly fitted into the console.

Step 7:

The *CapCoder* base assembly was mounted on the G90 front plate from the back with an M3x10 mm screw and serrated washer. The wires were carefully threaded through the small rectangular hole in the base assembly and the front plate was screwed to the console. Then using tweezers the wires were soldered to the appropriate copper pads and pushed back into the hole as far as possible.

Figs. 18 and 19 are close-ups of the base assembly mounted on the G90 front plate, please learn from these figs. how and where to solder the components, wire bridges and wires coming from the controller board.

fig. 18 - Mounted base assembly as seen from the front left.

fig. 19 - Mounted base assembly as seen from the front right.

The two holes for the push-button and LED in the cover assembly were masked on the inside with a small strip of sticky tape, then the assembly was laid with the open side down onto a piece of cardboard and coated with black matte acrylic spray paint taking care that no paint gets inside. Finally it was attached to the base assembly and secured with a black plastic washer and the push-button's nut.

I must admit that this project would have been predestined for SMD construction. However, having no experience with that I sticked to conventional components.

operation

During power-up of the G90 keep your hands away from the left and right sensor-plate of the *CapCoder*, because an automatic sensitivity calibration of both sensors is done. After that very short initial calibration phase the red LED lights up for two seconds. If no sensor is touched when the LED goes off normal operation commences.

However, if a sensor is touched the LED displays four 2-digit numbers in slow Morse code. The first value pair is preceded by an "R" for the right sensor, the second by an "L" for the left sensor. The first value of each pair is the calibration-value and the second is the touch-value of that sensor giving double the sensor capacitance in pF (the maximum possible value is 64 = 32 pF). For example "R 04 42 L 06 07" means that the non-touched calibration capacitance was 2 pF for the right sensor / 3 pF for the left sensor and when a sensor was touched (when the LED went out) the capacitance was 21 pF for the right sensor / 3.5 pF for the left sensor. Thereafter *CapCoder* resumes normal operation.

During normal operation *CapCoder* mimics a rotary encoder which tunes the frequency continuously up while only the right sensor is touched and down while only the left sensor is touched . In this mode the tuning rate is about 20 steps = 200 Hz per sec. @ 10 Hz steps for slow tuning. A prolonged pause of 0.1 sec. after the initial tuning step allows for easy one-step fine tuning and setting of user defined functions. As soon as also the other sensor is touched the tuning rate increases tenfold to 200 steps = 2 KHz per sec. for fast tuning. The push-button has the same functionality as with the original encoder.

When the G90 is powered from an SMPS (switched-mode power supply) chances are that you might encounter erratic tuning behaviour like mssing tuning steps and fast tuning only in one direction. Here is why and how to solve it:

Any mains-powered appliance with exposed metal should have the metalwork earthed to the mains supply and the 0 V (neutral) output of switching supplies is normally also connected to mains earth. The exception are small adapters and laptop supplies which are *double insulated* and therefore do not need and in most cases do not have a mains earth connection.

The AC input circuitry of a switching supply includes so-called X and Y capacitors for interference suppression in order to improve EMC. In a typical SMPS input filter two Y capacitors of equal value are connected in series across the input and their common connection goes to the 0 V output, so that they are acting as voltage divider and about half of the input AC voltage appears on the usually "neutral" output. In supplies where the 0 V output is connected to mains earth, the leakage current caused by this capacitor flows back to mains earth. However, in double-insulated supplies with no mains earth, this is one reason why you will feel a "tingle" or "rubbing sensation" if you stand in bare feet and touch the supply output or metal cabinet of the powered device with a sensitive part of your body such as the back of your middle finger. The leakage current is not enough to be dangerous, but it is detectable.

fig. 20 - AC voltage on G90 cabinet when powered by SMPS.

I bought a *Pro Audio Engineering* model PAE-Kx33 Low-RFI SMPS to power my G90, fig. 20 shows the 50 Hz AC voltage measured between the G90 cabinet and mains earth: 162 Vpk which is exactly half of our 230 Vrms = 325 Vpk mains voltage, and this high AC voltage caused the described erratic operation of *CapCoder*. The cure is very simple: a wire connecting the G90 cabinet to mains earth now keeps it really neutral and resolved the issue. This connection is sometimes made inadvertently, for example when the attached coaxial cable goes to an antenna switch with connection to another radio set which is earthed to mains earth. And beyond that it is still safe and wise to connect the 0 V output of a double insulated SMPS to mains earth if available.

Any suggestions, feedback and comments are welcome.

references

1. http://cq-cq.eu/DJ5IL_rt011.pdf (click URL to open)
2. http://www.youtube.com/watch?v=v_NOptLdGtM (click URL to open)
3. http://cq-cq.eu/capcoder.hex (click URL to download)

DJ5IL_rt013.pdf
Original version: 3.6.2022
Revisions: