HABS_CYBERSQUAD – 22903B

REVERSE ENGINEERING AN RCBO– BY OSCAR & AYAAN

HERTFORDSHIRE, UNITED KINGDOM

WHAT IS AN RCBO AND WHY DID WE CHOOSE IT?

Fig 1.3, A generic,
British consumer unit fitted with RCBO's (Single Phase.)

Fig 1.2, a GFCI Breaker (North America.)

Fig 1.1, The Wylex 16A Type B RCBO that we reverse engineered.

For our Reverse Engineering project, we are examining a Wylex 16 Amp type B RCBO, which serves as a Residual Current Breaker with Over-current. This device detects imbalances between live and neutral conductors and excess current draw, tripping to isolate the circuit. It's designed for single-phase residential applications, commonly found in consumer units or electrical panels. In the US, it's called a GFCI and is mainly used in washrooms and near water sources, while in the UK, all outlets require RCD protection. Our goal is to reverse engineer this device due to its global importance in electrical safety. Electricity has revolutionized our way of life, powering homes, businesses, transportation, and communication networks.
HABS_CYBERSQUAD PRESENTS…

REVERSE ENGINEERING AN RCBO!

INCREASING MARKET FOR RCBO'S

Before the 16th amendment to BS7671 in 2008, RCD protection wasn't mandatory for all circuits in a building. After the amendment, nearly all circuits were required to have RCD protection. In recent years, RCBOs have gained popularity for homeowners and landlords seeking cost-effective alternatives to RCCBs and MCBs. RCBOs can pass electrical safety tests for up to 30 years and are practical because they trip only the individual circuit, preserving power to essential devices like fridges and freezers. They also offer improved safety, as they won't cut power to lighting and smoke alarms in case of a trip, unlike RCCBs. While specific usage data is unavailable, the trend shows increased adoption of RCBOs in installations.

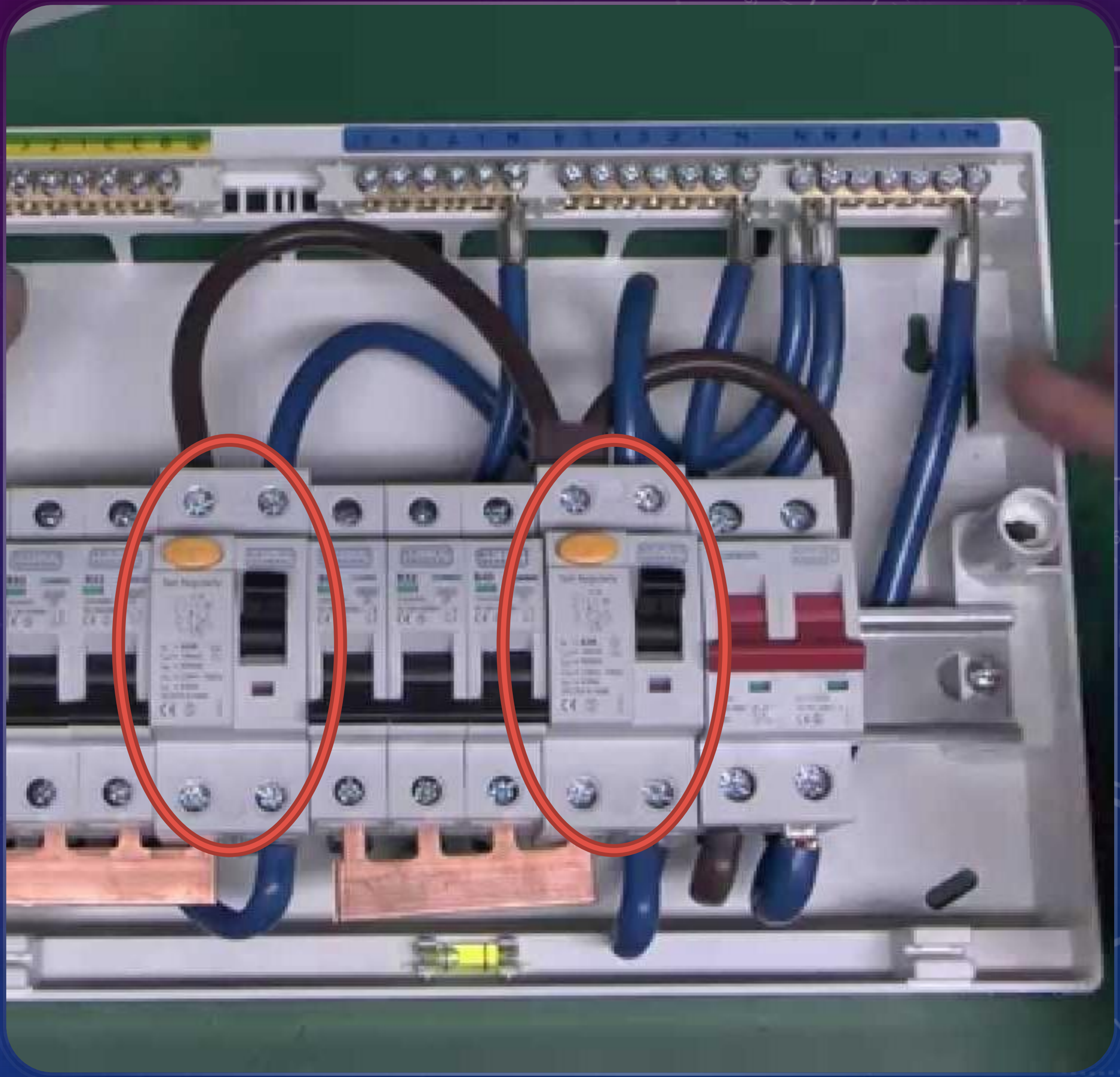
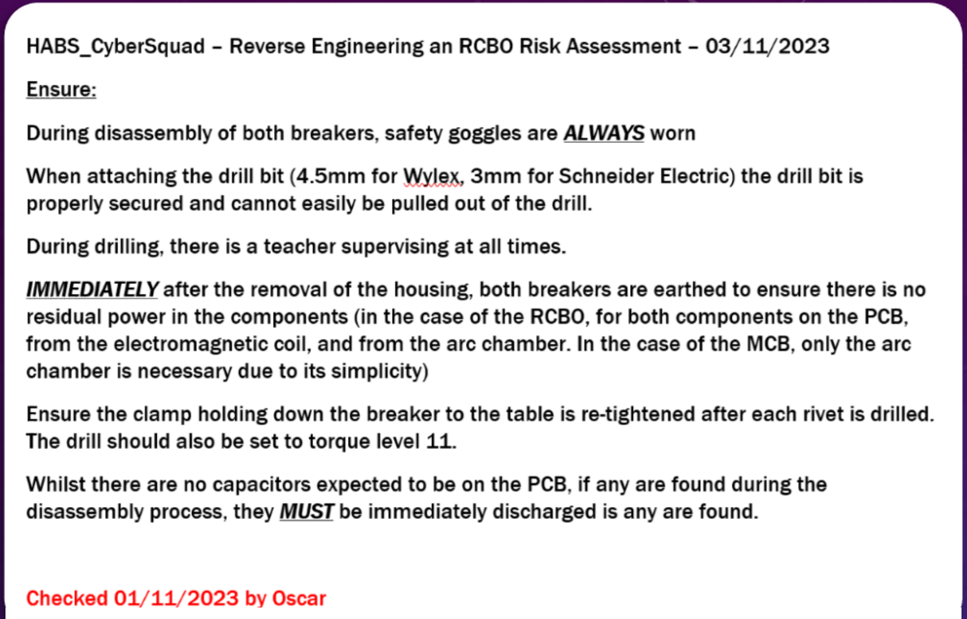


Fig 1.4 Split load consumer unit with 2 RCCB's and 3 MCB's per RCCB. The RCCB's are circled in red. This was what was formerly used in the UK.

SAFETY & HAZARDS DURING DISASSEMBLY



HABS_CyberSquad – Reverse Engineering an RCBO Risk Assessment – 03/11/2023

Ensure:

During disassembly of both breakers, safety goggles are ***ALWAYS*** worn

When attaching the drill bit (4.5mm for Wylex, 3mm for Schneider Electric) the drill bit is properly secured and cannot easily be pulled out of the drill.

During drilling, there is a teacher supervising at all times.

IMMEDIATELY after the removal of the housing, both breakers are earthed to ensure there is no residual power in the components (in the case of the RCBO, for both components on the PCB, from the electromagnetic coil, and from the arc chamber. In the case of the MCB, only the arc chamber is necessary due to its simplicity)

Ensure the clamp holding down the breaker to the table is re-tightened after each rivet is drilled. The drill should also be set to torque level 11.

Whilst there are no capacitors expected to be on the PCB, if any are found during the disassembly process, they ***MUST*** be immediately discharged is any are found.

Checked 01/11/2023 by Oscar

Fig 1.5 Risk Assessment for Disassembly.

Fig 1.6 Safety goggles we used during disassembly (same brand.)

Upon selecting the RCBO for reverse engineering, we obtained approval from our supervisor. Safety precautions were diligently followed during disassembly. We wore safety goggles (Fig 1.6), ensured all power was disconnected, and capacitors were discharged. An online photo reference was consulted to identify potential charge-holding capacitors. We found one small capacitor under the PCB, which was safely discharged. A personalized risk assessment was conducted (Fig 1.5) to underscore our commitment to safety, recognizing that the RCBO may have been in use, potentially harboring residual power.

DAY 1 – DISASSEMBLY & RESEARCH

Fig 2.3, A Schneider Electric 3A MCB.

Fig 2.2, Rivets on the Schneider Electric MCB (Circled in red.)

Fig 2.1, Rivet holes on the Wylex 16A Type B RCBO (Circled in red.)

The disassembly process of the Wylex RCBO and similar consumer unit devices proved challenging due to their robust, long-lasting design aimed at preventing any exposure of live parts. The enclosure was fastened together with 8 rivets that could be drilled out. The RCBO had an IP20 rating, ensuring protection against objects over 12mm, such as fingers.

Our research was extensive as limited information was available from Wylex, a non-mainstream competitor. This project required a combination of common sense and online resources for reverse engineering. To aid our understanding, we acquired and disassembled a Schneider Electric 3A Type B MCB to differentiate the RCD and MCB components, given the standard nature of the MCB in RCBOs across manufacturers. An MCB just has overcurrent and short circuit protection, not earth protection unlike the RCBO

DISASSEMBLY & RESEARCH

We utilized a DeWalt hand drill with a 3mm bit for the MCB and a 4.5mm bit for the RCBO, as the rivet sizes varied. To accurately measure the holes, calipers were used (Fig 2.8). We proceeded by removing the RCBO's locking pins with needle-nose pliers and a center punch, followed by carefully prying open the top housing using a flathead screwdriver. This revealed the complexity of the breakers, but the MCB assisted in distinguishing components related to the RCD and MCB functions within the RCBO.

Fig 2.6 The locking pins found on both breakers.

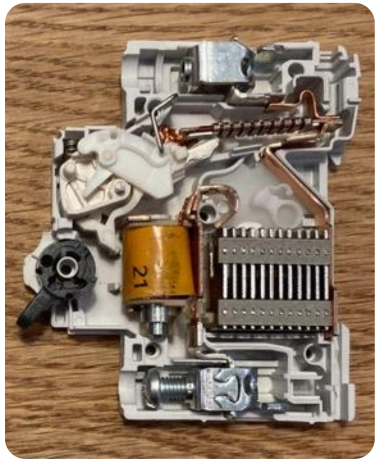


Fig 2.5 The inside of the Schneider Electric MCB.

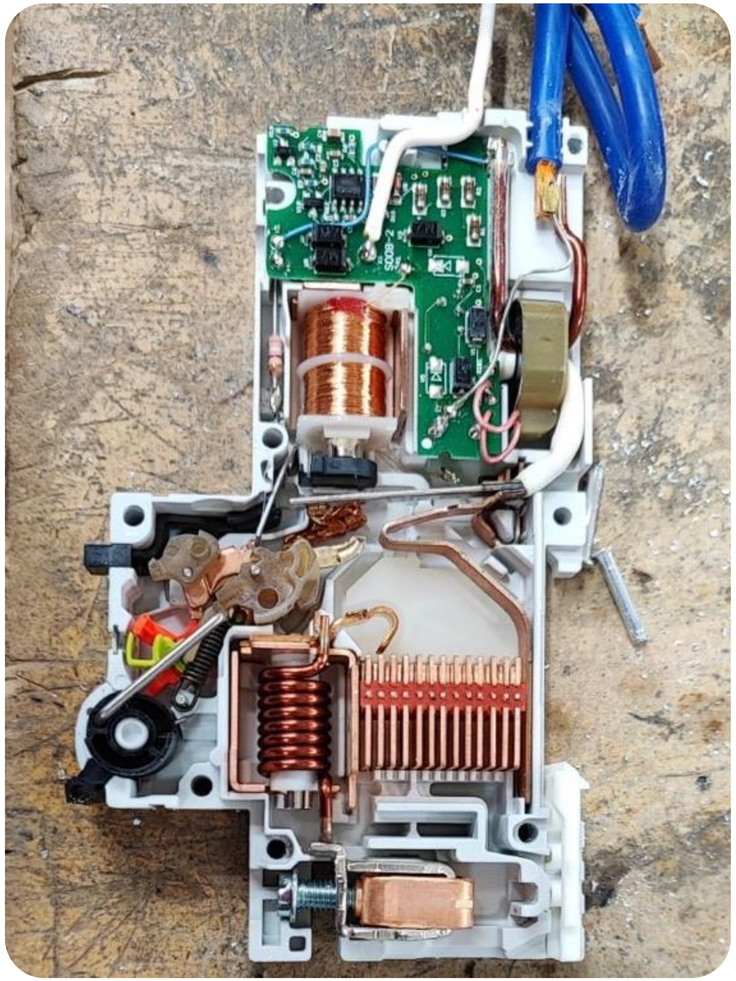


Fig 2.4 The internal components of the Wylex 16A RCBO.

MEASUREMENTS & DIMENSIONS

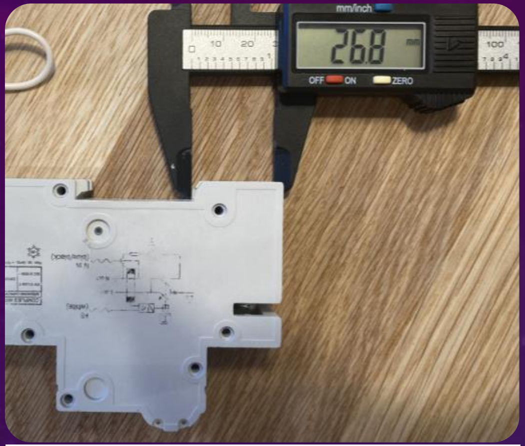


Fig 2.7 26.8mm 1.05"

We also took some measurements of both breakers using calipers. As can be seen in Fig 2.1 and 2.2, the RCBO is noticeably larger than the MCB since it houses more circuit protection. In fact, in Fig 2.4, you can see that the bottom part of the Wylex breaker is essentially the MCB (Fig 2.5) without screw terminals. The measurements are in metric (mm) and imperial (“).

Fig 2.8 4.5mm 0.17"

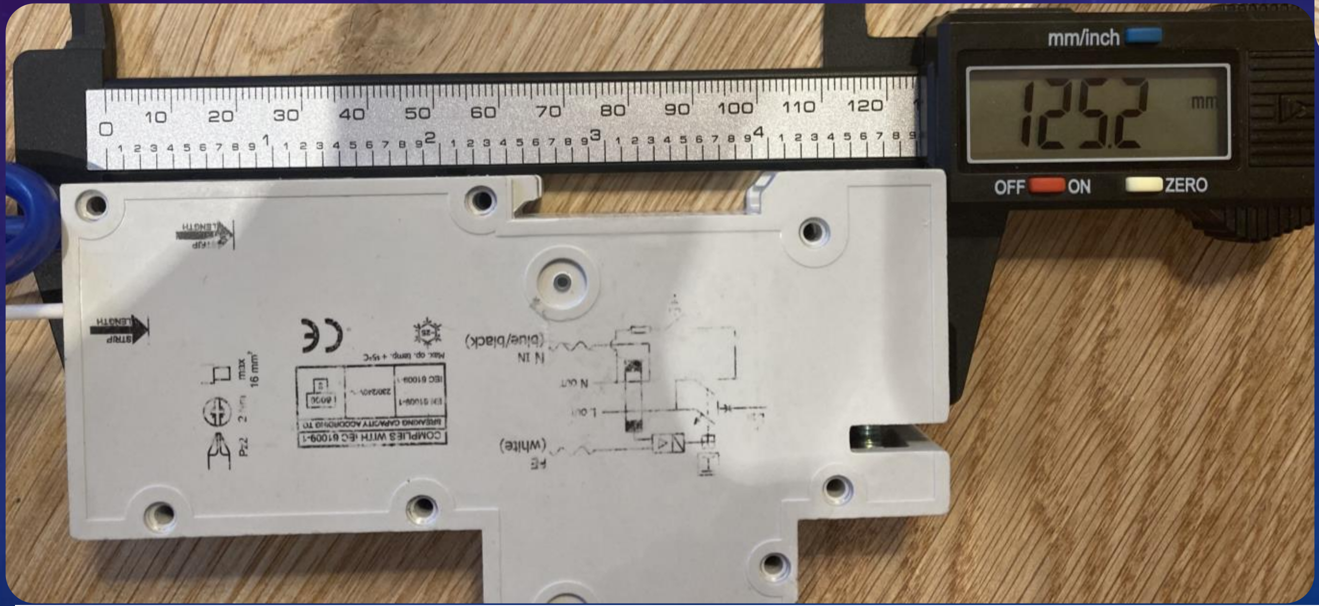


Fig 2.9 125.2mm 4.92"

Fig 2.10 6.2mm 0.24"

Fig 2.7 = Length under DIN rail mount.

Fig 2.8 = Rivet hole diameter (after drilling.)

Fig 2.9 = Entire length.

Fig 2.10 = Screw terminals.

MEASUREMENTS & DIMENSIONS

Fig 2.10 = DIN rail mount length.

Fig 2.11 = Width (From Top.)

Fig 2.12= Width (From Bottom.)

Fig 2.13 = Length on top of DIN rail mount.

Fig 2.14 = Length of Switch enclosure.

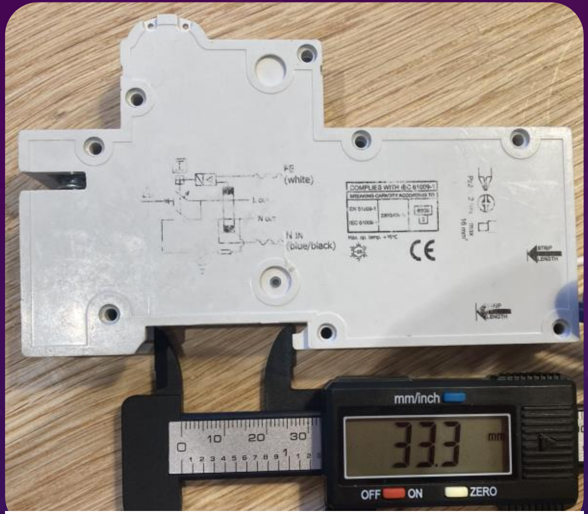


Fig 2.10 33.3mm 1.31"

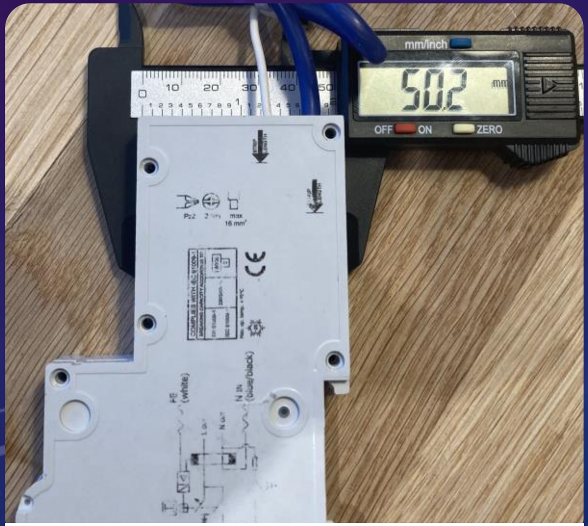


Fig 2.11 50.2mm 1.97"

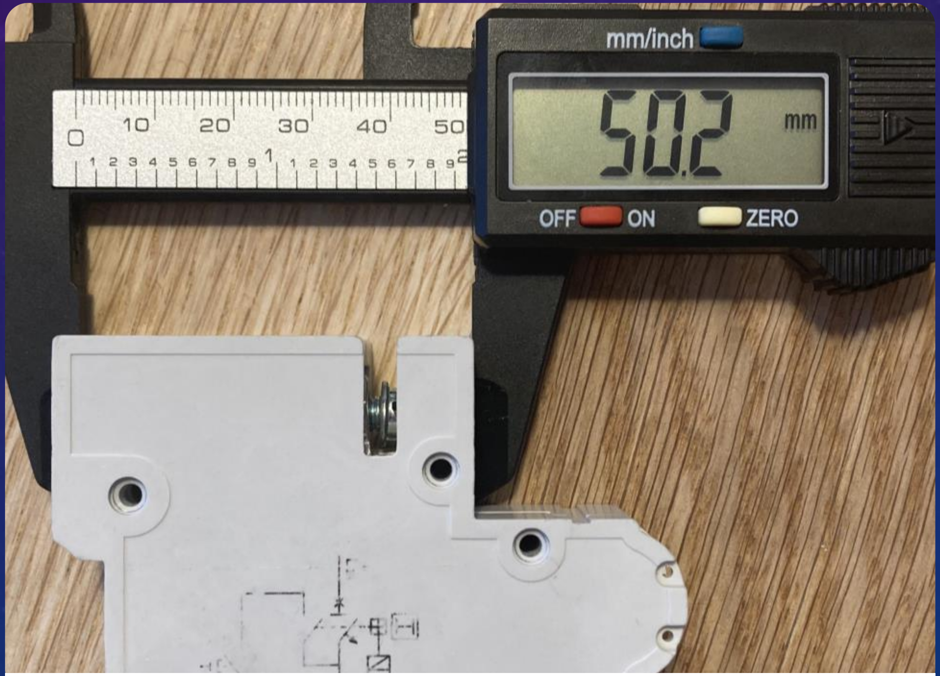


Fig 2.12 50.2mm 1.97"

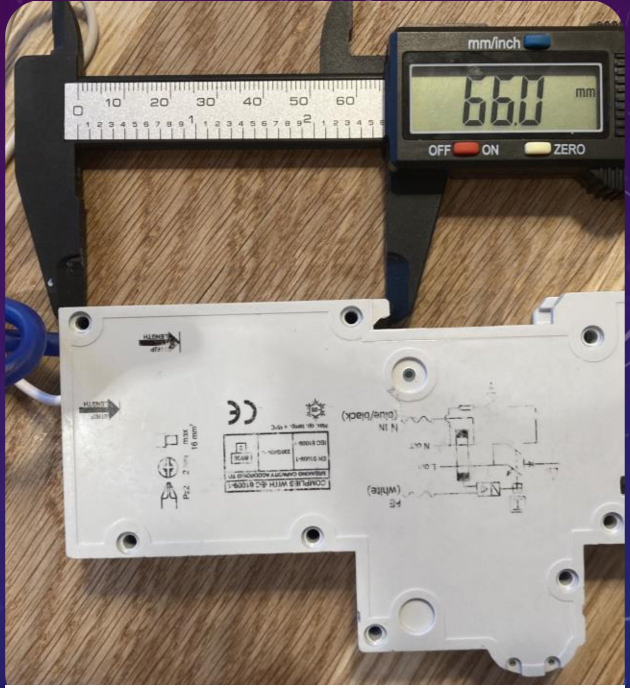


Fig 2.13 66.0mm 2.59"

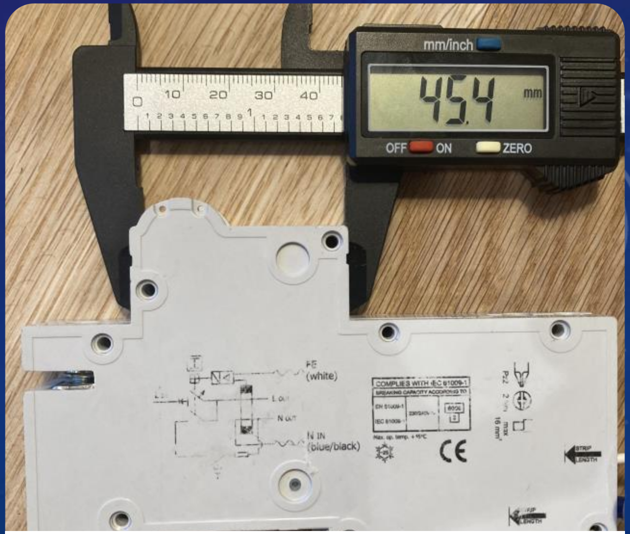
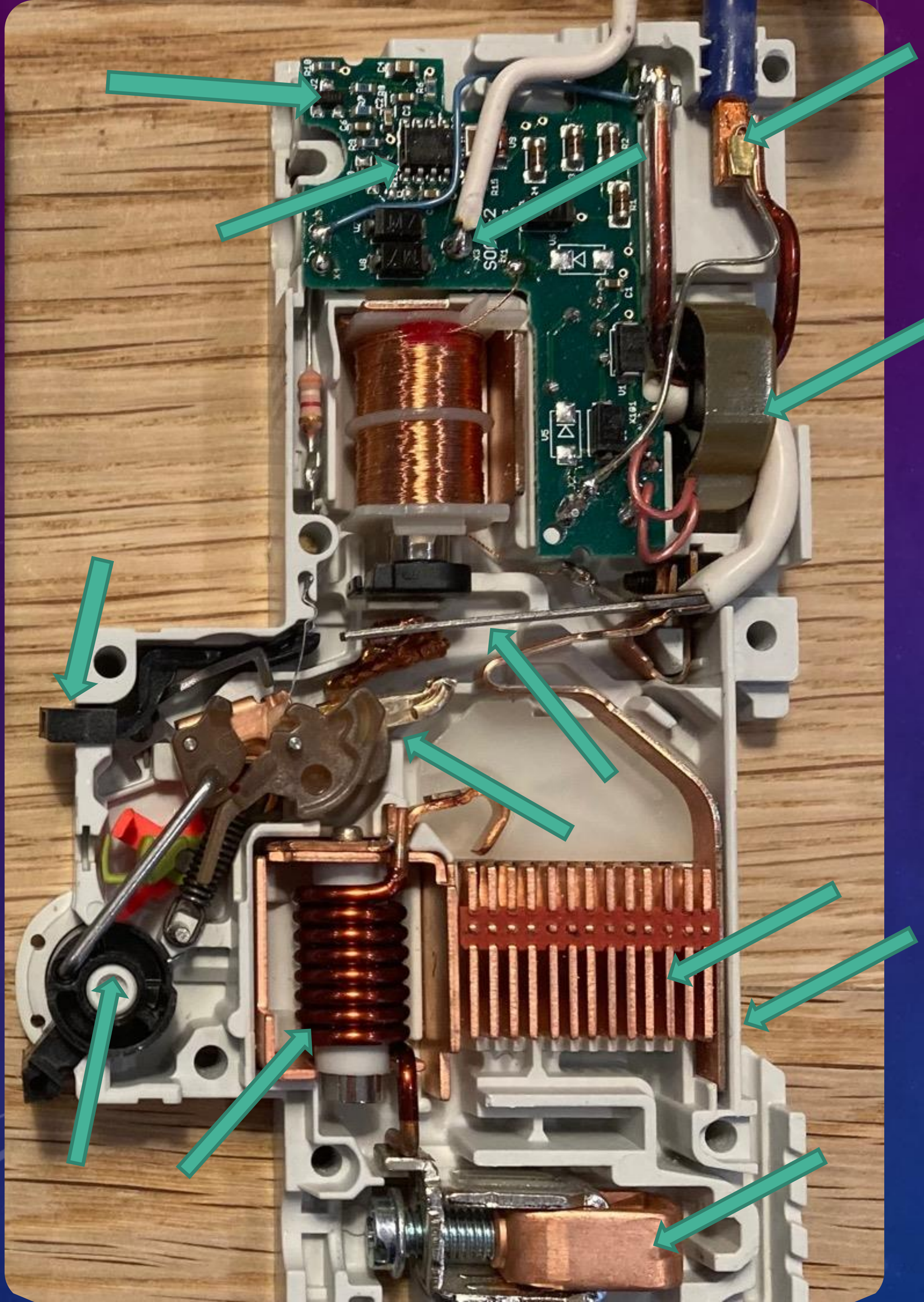


Fig 2.14 45.4mm 1.78"



DAY 2 – DECONSTRUCTION OF INTERNALS & PARTS LIST

On day 2 of the project, we started to analyze what some of the parts might be. In some cases, we had to use our common sense (such as the neutral in and functional earth), and for others, we found documentation online (such as the electromagnetic relay). Here is a parts list of of the components in the RCBO and their function.

Please press on the arrows to look at a specific component.

The Parts List is from Pg 9-17.

PCB (PRINTED CIRCUIT BOARD)

Return to Parts List

The PCB of the RCBO is part of the RCD side of the breaker and is located at the very top of the breaker. It connects to the FE (Functional Earth) and Neutral conductor, to the testing resistor (See more on Pg. 14) and to the Differential Current Transformer. Effectively, all the key components of the RCD are connected to the PCB , as it is the component that would send the signal for the Circuit Breaker to trip. As you can see, the PCB mainly consists of M7 diodes and different types of resistors, but there were also two components which we believe to be MOSFET's or some other kind of transistor. We also found the M54123L microchip, which after reading the manufacturers datasheet we found out is the component that detects the leakage current. It takes the output from the DCT and after 30mA of leakage is detected, will trip the breaker.

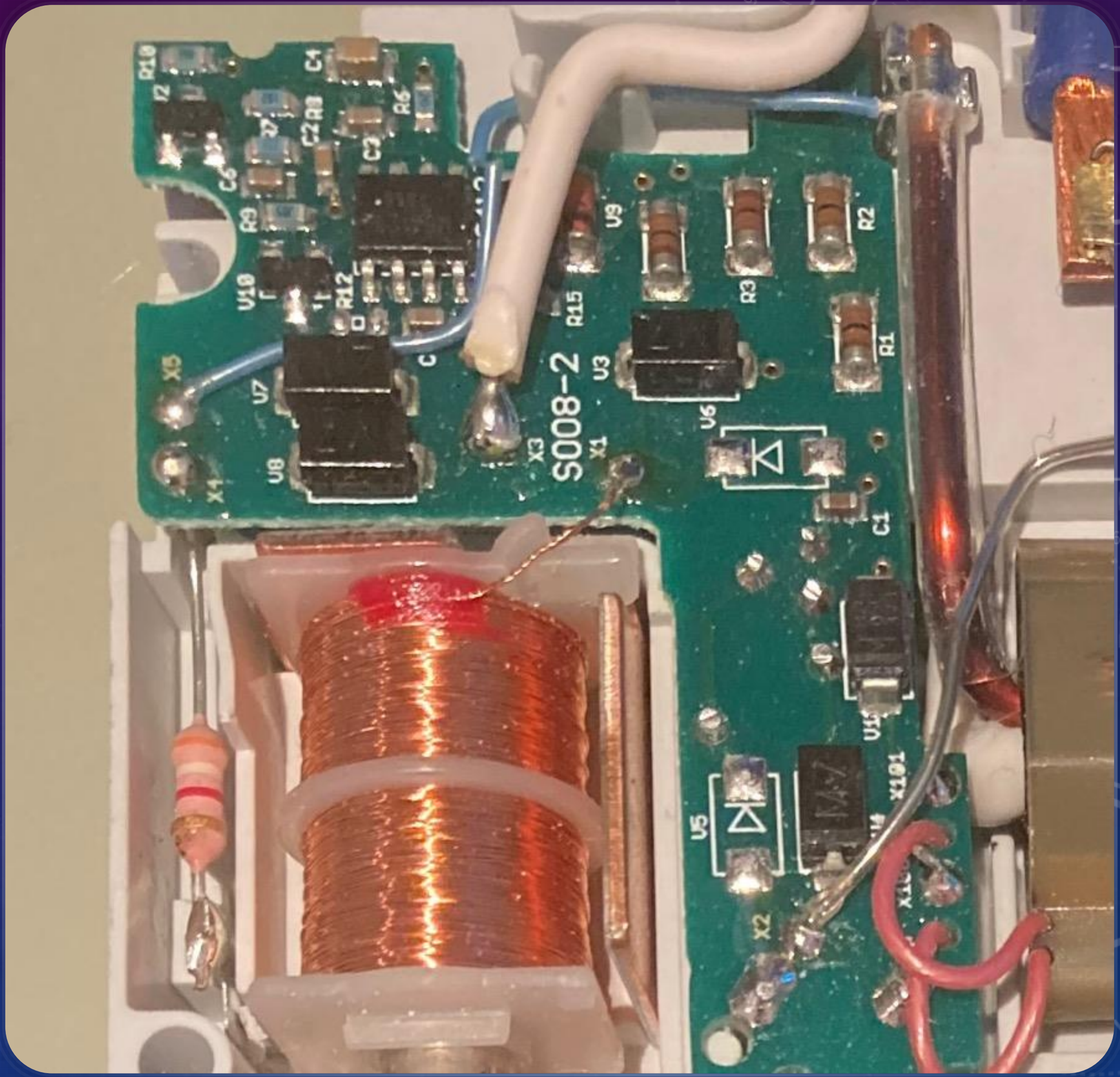


Fig 3.1 The PCB of the Wylex 16A RCBO

M54123L IC (INTEGRATED CIRCUIT)

Return to Parts List

The Unisonic Technologies M54123L IC (Fig 3.5) is the component that is responsible for handling the earth fault protection on the breaker. This means if there is an imbalance between the Live and Neutral conductors, the breaker should trip, as the current is going elsewhere. The breaker receives various inputs, such as the DCT, the testing mechanism and earth, and can output a current to the trip coil that will open the contacts and shut off the breaker. By looking at Fig 3.4, we can see that the breaker is designed to trip at around 30mA, ensuring there is not a fatal shock if the imbalance is going through someone's body. All of this (according to Fig 3.4) should happen in only 4ms. We can see in Fig 3.3 that the M54123L is the brain of the PCB, and controls all RCD functionality that the RCBO has.

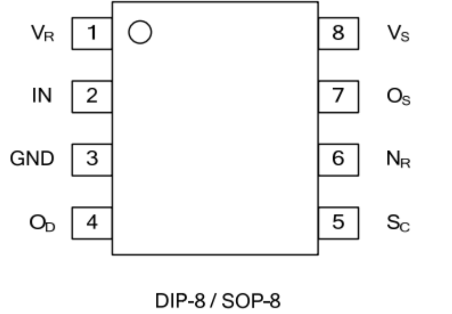
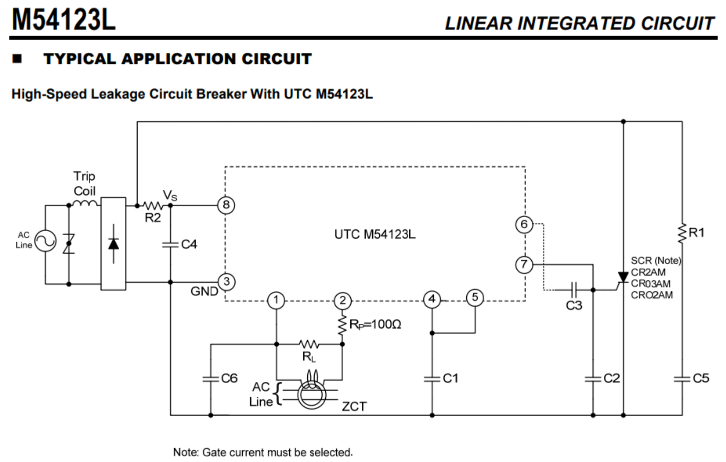


Fig 3.2 Pin Out



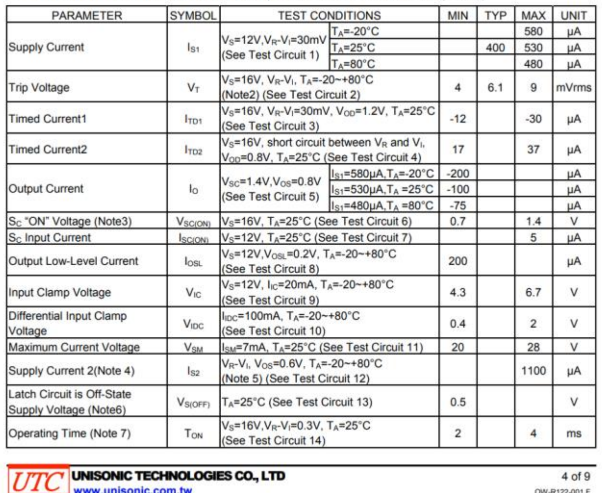
M54123L *LINEAR INTEGRATED CIRCUIT*

■ **TYPICAL APPLICATION CIRCUIT**

High-Speed Leakage Circuit Breaker With UTC M54123L

Note: Gate current must be selected.

Fig 3.3 Application circuit for the RCBO



■ **ELECTRICAL CHARACTERISTICS** (T_A=-20~+80°C, unless otherwise specified)

PARAMETER	SYMBOL	TEST CONDITIONS		MIN	TYP	MAX	UNIT
Supply Current	I_{S1}	V_S=12V,V_R-V_I=30mV (See Test Circuit 1)	T_A=-20°C			580	μA
			T_A=25°C		400	530	μA
			T_A=80°C			480	μA
Trip Voltage	V_T	V_S=16V, V_R-V_I, T_A=-20~+80°C (Note2) (See Test Circuit 2)		4	6.1	9	mVrms
Timed Current1	I_{TD1}	V_S=16V, V_R-V_I=30mV, V_{OD}=1.2V, T_A=25°C (See Test Circuit 3)		-12		-30	μA
Timed Current2	I_{TD2}	V_S=16V, short circuit between V_R and V_I, V_{OD}=0.8V, T_A=25°C (See Test Circuit 4)		17		37	μA
Output Current	I_O	V_{SC}=1.4V,V_{OS}=0.8V (See Test Circuit 5)	I_{S1}=580μA,T_A=-20°C	-200			μA
			I_{S1}=530μA,T_A =25°C	-100			μA
			I_{S1}=480μA,T_A =80°C	-75			μA
S_C "ON" Voltage (Note3)	$V_{SC(ON)}$	V_S=16V, T_A=25°C (See Test Circuit 6)		0.7		1.4	V
S_C Input Current	$I_{SC(ON)}$	V_S=12V, T_A=25°C (See Test Circuit 7)				5	μA
Output Low-Level Current	I_{OSL}	V_S=12V,V_{OSL}=0.2V, T_A=-20~+80°C (See Test Circuit 8)		200			μA
Input Clamp Voltage	V_{IC}	V_S=12V, I_{IC}=20mA, T_A=-20~+80°C (See Test Circuit 9)		4.3		6.7	V
Differential Input Clamp Voltage	V_{IDC}	I_{IDC}=100mA, T_A=-20~+80°C (See Test Circuit 10)		0.4		2	V
Maximum Current Voltage	V_{SM}	I_{SM}=7mA, T_A=25°C (See Test Circuit 11)		20		28	V
Supply Current 2(Note 4)	I_{S2}	V_R-V_I, V_{OS}=0.6V, T_A=-20~+80°C (Note 5) (See Test Circuit 12)				1100	μA
Latch Circuit is Off-State Supply Voltage (Note6)	$V_{S(OFF)}$	T_A=25°C (See Test Circuit 13)		0.5			V
Operating Time (Note 7)	T_{ON}	V_S=16V,V_R-V_I=0.3V, T_A=25°C (See Test Circuit 14)		2		4	ms

UTC UNISONIC TECHNOLOGIES CO., LTD
www.unisonic.com.tw
4 of 9

Fig 3.4 Electrical characteristics

Fig 3.5 M54123L housing

SCREW TERMINALS & DIN RAIL CONNECTION

Return to Parts List

The screw terminals on the breaker are connected to 3 places. In terms of the neutral in, that is connected to the bar with the blue wires in it in Fig 3.9. The neutral out would go to the circuit which the breaker is protecting.

Fig 3.9 British Consumer unit (for reference.)

The Live in would come from the double—pole (meaning two conductor) Main Switch in red (on the far right of Fig 3.9) through a Bus Bar (the little copper strip at the bottom of Fig 3.9) The Live conductor comes into the Consumer Unit through the brown wire coming out of the top of the red double-pole breaker. The Live out would also go to the Live conductor of the circuit the breaker is protecting.

The Functional Earth conductor is cream in color and goes into the green-yellow striped
Bar at the top of Fig 3.9.

The DIN rail is the standard connection standard for all consumer unit accessories. It connects via the rail in Fig 3.8 to the back of the breaker. The rail connects to the mount seen in Fig 3.6 on the Wylex 16A RCBO.

Fig 3.8 a DIN rail with a breaker attached.

Fig 3.6 DIN Rail Mount.

Fig 3.7 Screw terminal (for Bus Bar connection.)

MAGNETIC COIL/SOLENOID & BIMETALLIC STRIP

Return to Parts List

- The Magnetic Coil (circled in green) and Bimetallic Strip arguably play the most important part of the breaker. Without them, if there was an electrical fault, the Breaker would not trip during a short circuit. The solenoid extends and pushes the plastic piece which disconnects the breaker. In the event of a short circuit, the coil attracts a metallic part of the trip, tripping the breaker as can be seen in Fig 3.10. The physical disconnect can be seen in Fig 3.11 (circled in red is the end of the bar that cuts the circuit during a short circuit.)

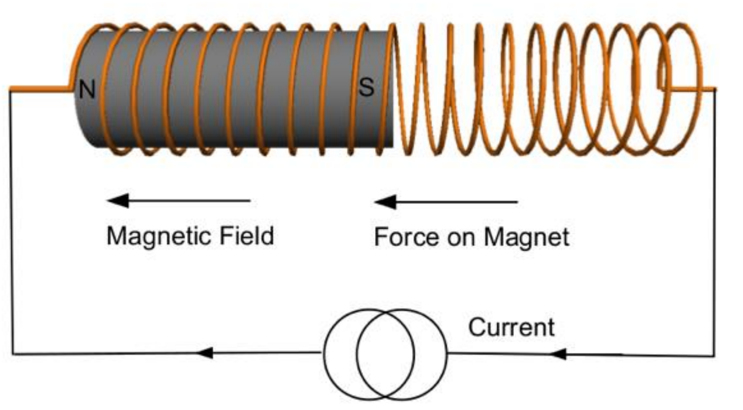


Fig 3.12 Simple workings of the Magnetic Coil/Solenoid.

Fig 3.11 Magnetic Coil/Solenoid.

The entire overcurrent part of the breaker is controlled by the bimetallic strip, which when a certain amount of current is passed through will bend, until it bends so much that a circuit is created between the strip and a spring-operated contact that is unlatched and trips the breaker. After the strip has cooled down, the breaker can be turned back on.

Fig 3.10 Bimetallic Strip.

ARC CHAMBER

Return to Parts List

The arc chamber is another fundamental part of the MCB part of the RCBO. During the disconnection of the breaker, the switching lever (circled in green) moves away from the copper strip beneath it. During this process, the high voltage and current can cause arcing, the process in which the electricity ionizes the air, effectively making the air conductive, meaning the breaker is still on, even if it not mechanically connected. The arcs can be many 1000's of degrees Fahrenheit , and the arc chamber aims to stop this arcing from happening by directing the power into the arc chamber (circled in red). In the chamber, the 13 fins split the formerly powerful arc into several smaller arcs, until the driving voltage is no longer sufficient for the air to remain ionized, and the arcs are extinguished. The arc chamber is effectively necessary in all switched breakers, which became popular in the mid-1960's. The path which the power flows during arcing can be seen in blue arrows (The switching lever is in the off (0) position in the diagram.)

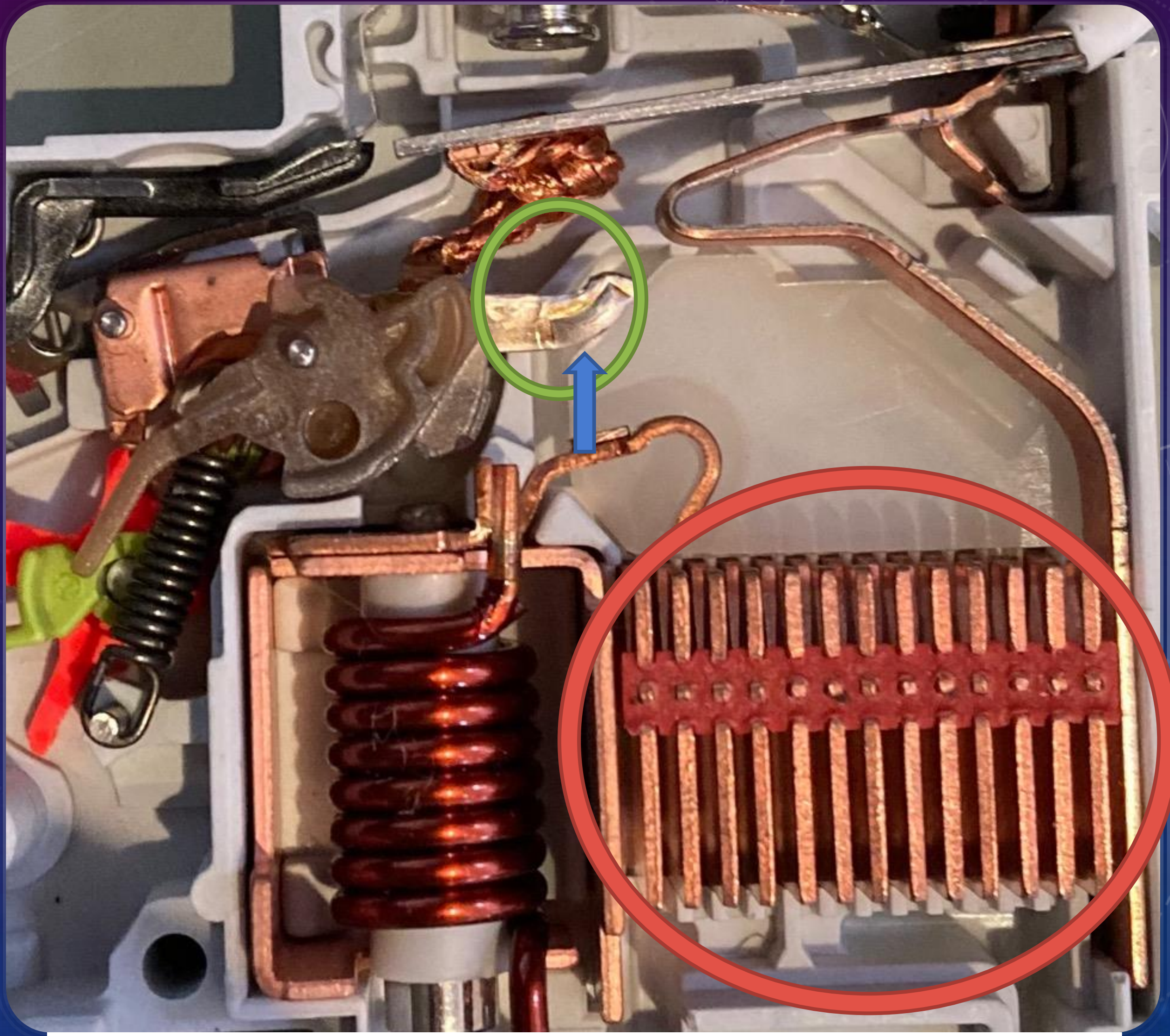


Fig 3.13 Arc chamber (circled in red) and switching lever (Circled in green) on the Wylex 16A Breaker.

RCD TEST ASSEMBLY

Return to Parts List

The RCD test assembly, whilst not necessary for the operation of the breaker, is a very important part of the safety of the RCD. It is so fundamental to the safety of an electrical instillation, that all British consumer units with RCD protection require a sticker (Fig 3.14) on their cover about when to test the RCD. The test button (bottom left of Fig 3.16) is depressed, which causes a plastic insert with a strip of copper at the end to contact with a conductive bar in the green circle on Fig 3.12 , which connects a circuit between the neutral in, a resistor with a resistance of 30mA, the PCB and the IC that handles the earth leakage protection. This IC simulates a 30mA leakage and should trip the breaker. If the breaker doesn't trip, the sticker in Fig 3.14 advises to "**seek expert advice**," and most likely means that the RCD part of the RCBO isn't functioning, which poses a risk to you, and everything connected to the circuit.

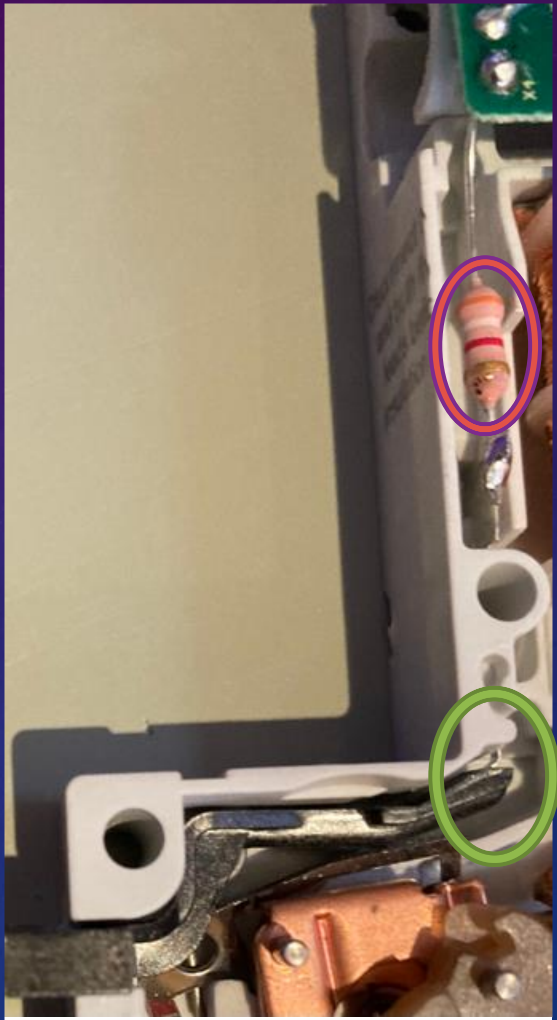
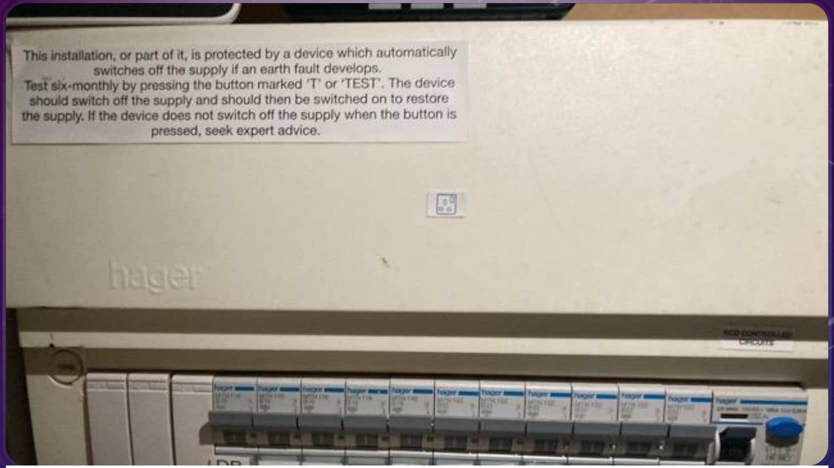


Fig 3.16 Side view of RCD test assembly.



This installation, or part of it, is protected by a device which automatically switches off the supply if an earth fault develops.
Test six-monthly by pressing the button marked 'T' or 'TEST'. The device should switch off the supply and should then be switched on to restore the supply. If the device does not switch off the supply when the button is pressed, seek expert advice.

Fig 3.14 Oscar's home consumer unit with RCD test assembly sticker (top left corner) and RCCB (The RCD protection, Bottom left.)

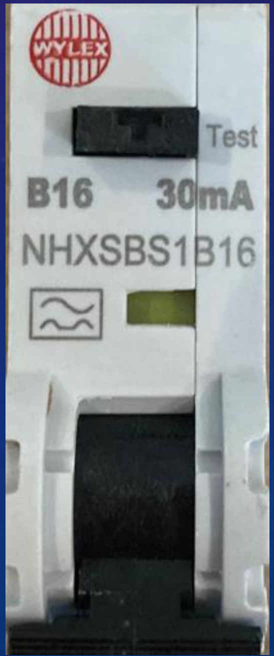


Fig 3.15 Front of the RCD testing assembly with push button and 30mA tripping rating.

DCT (DIFFERENTIAL CURRENT TRANSFORMER)

Return to Parts List

The DCT is the most important part of the RCD. The RCD is effectively centered around the DCT, as it is the part that can detect if there is a difference in the current flowing through the live to neutral conductor. If there is a difference, that current could potentially be flowing through someone who's earthed (touching the literal earth or a bare piece of metal such as a toaster). The current transformer has the earth and live wire passing through it (in Fig 3.18, Neutral is the brown, copper colored thick cable, and the Live is the wire wrapped in the white insulation material), and, if a difference is detected, will signal the trip coil (connected to the DCT via the two red wired in Fig 3.19 coming out of the side of the transformer and into the PCB), which will then disconnect the switching lever, tripping the breaker. The DCT is the reason why the RCBO must have a neutral connection, as it must ensure that the same current leaving the breaker is the same that's returning.

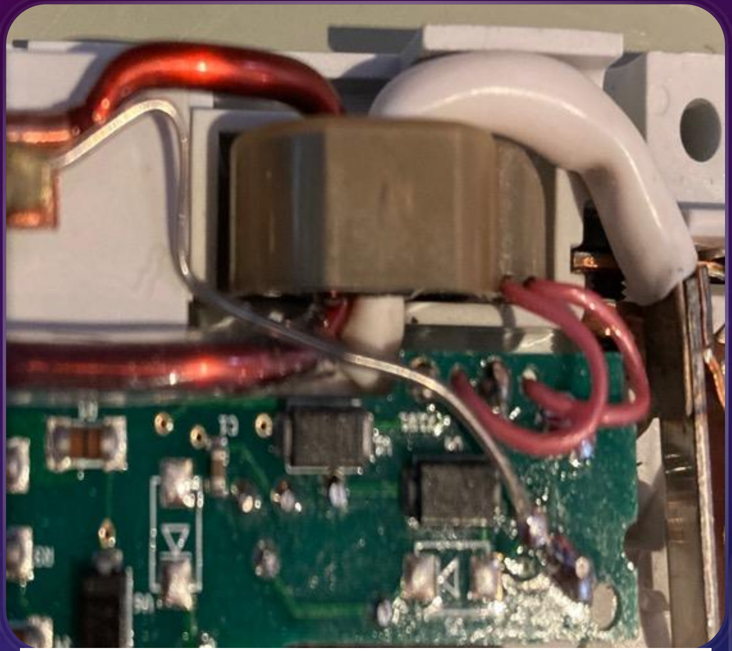


Fig 3.18 The DCT in the RCBO.

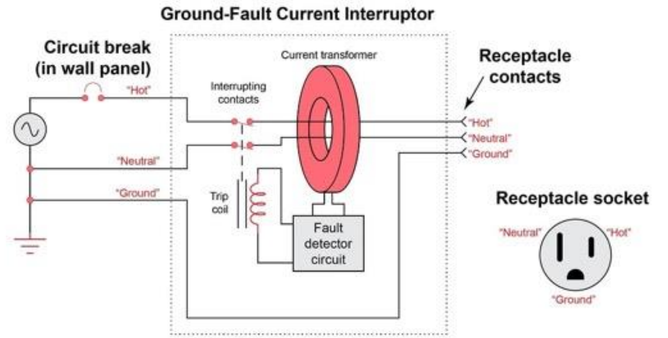
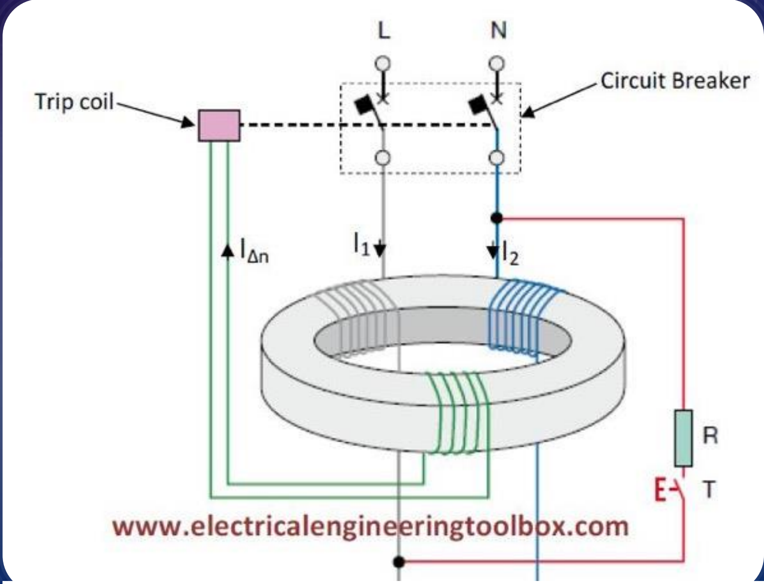


Fig 3.19 A DCT example in a GFCI (North American equivalent of RCBO) "Hot" is another name for the Live conductor.



www.electricalengineeringtoolbox.com

Fig 3.17 DCT wiring diagram. (Note that the neutral shouldn't be switched in the circuit breaker part of the diagram.)

SPRING LOADED CONTACT & SWITCH MECHANISM

Return to Parts List

The spring-loaded contact and switch mechanism, whilst looking quite complex in a side view photo, is actually very simple. The mechanisms are part of both the MCB and RCD mechanisms, are effectively a switch. When the switch is pulled down, the spring in the center of the photo pulls down the spring-loaded contact, which is designed to stay in the normally open state, as even though the breaker will probably stay on for most of it's use, for safety purposes, it would be better for the breaker to disconnect, than too not and to cause potentially life-threatening damage. The spring-loaded contact connects a circuit between two strips of copper, one of which is a flexible piece of copper from the bi-metallic strip in the top right corner, and the other is just after the magnetic coil/solenoid and has a green arrow pointing too it. When the breaker is activated, the electrons flow through the spring-loaded contact, through a piece of copper (not visible) and into the bi-metallic strip. The green and red signs can be seen in Fig 3.11 and are controlled by a spring under the black plastic switch part. Red indicated that the circuit is live and green indicates the circuit is disconnected, or the breaker tripped.

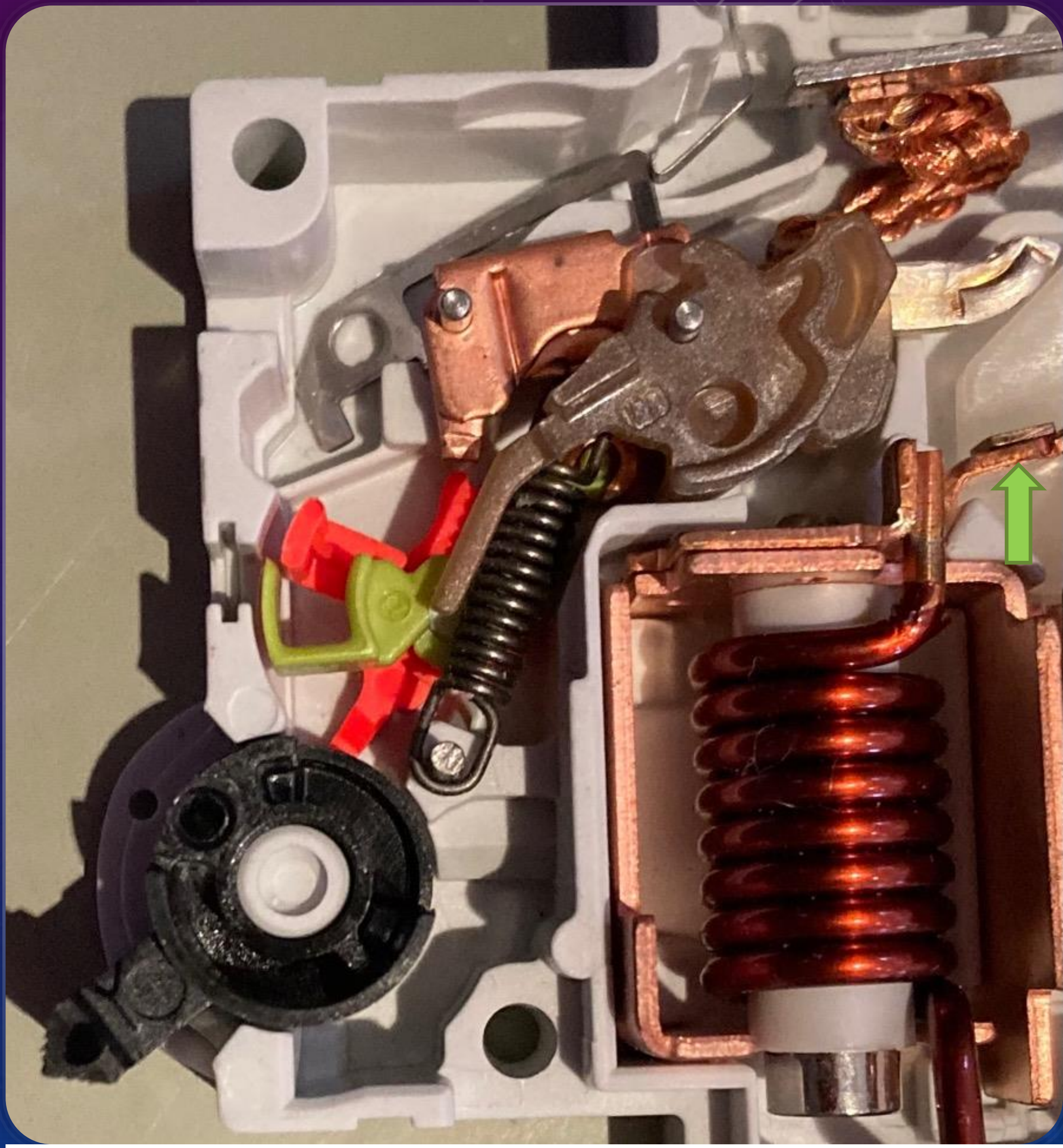


Fig 3.20 The Switching mechanism and spring loaded contact in the RCBO

DAY 3 - CONCLUSION & WHAT WE'VE LEARNT

In conclusion, our project on Deconstructing of an RCBO was a great opportunity to learn about how these devices work. By carefully deconstructing the breaker and examining its components, we were able to gain a better understanding of how it detects and protects against electrical faults.

Here are some of our key takeaways from the challenge:

- RCBOs are electrical safety devices that protect against electric shock and fire.
- RCBOs work by detecting imbalances in the current flowing through the two conductors of a circuit.
- If an imbalance is detected, the RCBO will interrupt the flow of current, preventing a shock or fire.
- RCBOs are an important safety feature in any electrical system.

We would like to thank the REC Foundation for providing us with this opportunity to learn about RCBOs. We hope that this challenge will help other students to gain a better understanding of these important safety devices.

You can find a summarized video version of our project here

Please note all wiring diagrams and colouring in the project are in the post 2008 wiring colours (Live = Brown, Neutral = Blue, Earth = striped yellow/green, functional earth = cream)

SOURCES (PG 1)

https://www.tlc-direct.co.uk/Images/Products/size_3/WYNSBS20BSLASH1.JPG Image on Page 1

https://www.eaton.com/content/dam/eaton/products/low-voltage-power-distribution-controls-systems/circuit-breakers/ch-circuit-breakers/CH-PON-circuit-breaker.jpg Fig 1.2

https://complete-electricians.co.uk/wp-content/uploads/2021/05/Screenshot-2021-05-11-at-20.22.47.png Fig 1.3

https://media.cylex-uk.co.uk/companies/2385/7022/images/Electrical-Fusebox_765239_large.jpg Fig 1.4

https://www.industrialworkwear.com/wp-content/uploads/2022/09/BBBS.jpg Fig 1.6

https://media.screwfix.com/is/image/ae235/8589P_A1?wid=257&hei=257&dpr=on Fig 2.3

https://www.unisonic.com.tw/uploadfiles/836/part_no_pdf/M54123L.pdf Fig 3.2 -3.4

SOURCES (PG 2)

https://upload.wikimedia.org/wikipedia/commons/thumb/6/6f/DIN_rail_rear_view.JPG/521px-DIN_rail_rear_view.JPG?20081027080111 Fig 3.8

https://madaboutelectrics.com/fuse-board-change%3F Fig 3.9

https://study.com/learn/lesson/circuit-breaker-types-purpose.html Fig 3.12

https://www.electricalengineeringtoolbox.com/2016/01/how-residual-current-device-rcd-works.html Fig 3.17

https://control.com/textbook/electric-power-measurement-and-control/differential-87-current-protection/ Fig 3.19

All other images in our project were taken by us

Thank You.