Tricks of the Trade

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Readers will have noted references to ‘safety’ in many previous articles in *Signal*. Essentially, ‘safety’ in the amateur context refers to protection of the equipment and protection to the operator. The criteria for safety in the broadcast transmission industry are the same as in the amateur context and this article explores the requirements and the ways these criteria are met and executed.

Protection of the equipment

The possible fault power levels in transmitters with input powers up to 600–1200 kW, DC voltages as high as 22 kV and deliverable current capacities up to 60 A, could be dramatic.

Figure 1. A typical high-wattage, low-value current-sensing resistor. It is the expanded metal element labelled as R122

Consider an HF sender with Class B modulation such as the Marconi Wireless Telegraph (MWT) 100 kW BD253 from 1961 or the MWT 250 kW BD272 from 1963. The HV was 11 kV and a pair of directly heated high power valves was used in the modulator with a similar, often identical, pair in the Class C RF unit. These valves were usually (steam) vapour cooled and risks of high current following loss of bias or a flash-over inside the valve can readily be imagined. Protection relays were installed with the coils paralleled across a low-value, high-wattage resistor (R122 in **Figures 1 and 2**) in the centre-tap connection of the filaments to chassis. When an over-current condition existed, the voltage across the resistor was sufficient to trip the relay. In practice a potentiometer was often added as part of R122, as well as a sensing circuit that provided ‘three-shot’ operation such that, after the first trip and restoration, a second trip could be registered and, if there was a third trip, the circuit would lock-out and there would be no further automatic restoration of HV. In later senders, *e.g.* the MWT B6124, a fraction of the voltage across the current-sensing resistor would be taken to one pin of an LM339 comparator IC with an adjustable reference on the other input pin and the logic circuits would initiate suppression of the HV.

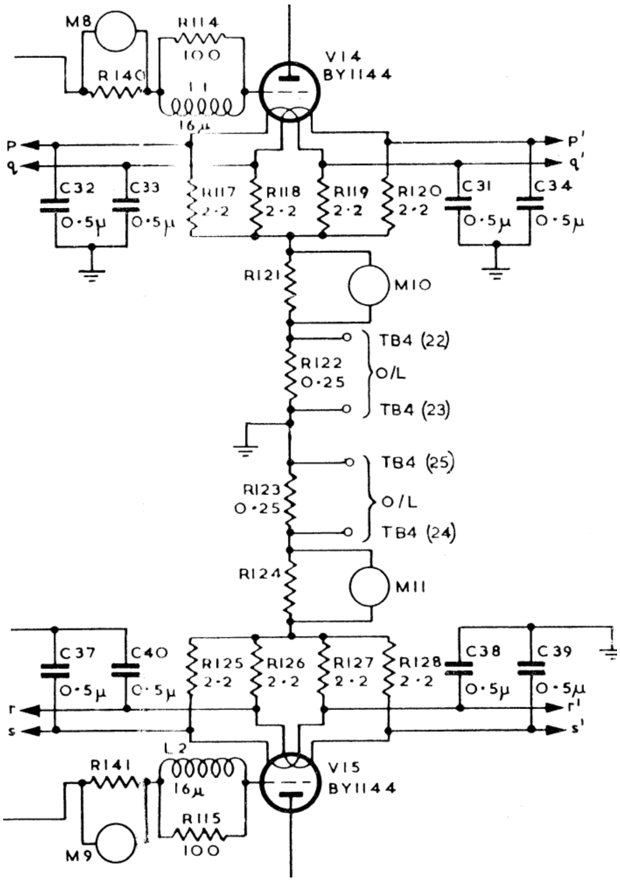

Figure 2. Circuit diagram of the over-current protection circuit involving R122

It is essential to monitor the feeds of cooling water for flow-rate and inlet temperature and suppress the HV in the event of coolant failure. Air blast-cooling is also used on filament seals and connections, and the integrity of the air-cooling system needs monitoring. Those who use forced air-cooled valves such as the 3CX or 4CX series will be well acquainted with the need to include an air-pressure switch to trip the heater and HV supply in the event of air flow failure. Damage through overheating can occur in a surprisingly short time.

At the time the 100 kW and 250 kW transmitters were developed, the 11 kV DC power supply used mercury arc rectifiers. Typically, EEV excitrons were used and, whilst they were physically compact, they required a comprehensive control circuit to establish, maintain and switch-off the supply both under normal and fault conditions. Many transmitter installations were converted to solid state rectification following the introduction of solid-state silicon rectifiers in the 1970s and 1980s. No doubt the non-technical accountants preferred this approach as excitrons were not cheap and did 'wear out' but, from an engineering perspective, it could almost have been viewed as a retrograde step as, only after the change, did certain disadvantages become apparent. In a fault condition, such as an overload in a valve, the time taken to suppress the HV was increased considerably over what had been the norm previously because, typically, three vacuum contactors in the AC supply feed to the rectifiers had to be opened; an electro-mechanical operation. Previously, electronic grid control of conduction in the excitron allowed the supply to be suppressed in a fraction of that time and the possible fault current was much reduced.

The cure, which could be considered 'brutal' by some, was to fit an additional vacuum contactor **(Figure 3)** across the main DC HV supply to earth, aka crowbar protection. Under normal operating conditions this switch was open but, when a fault was detected and the main trio of contactors opened, the crowbar switch would effectively short the HV supply to earth. At Woofferton, an engineer, Mark Edwards GW4LHL, who was a talented cartoonist, drew on the white ceramic-bodied switch a large crow perched on a reinforced steel joist in cross-section; there was no doubting the crowbar switch.

Figure 3. An 'un-illustrated' crowbar switch in the MWT BD272 sender

The change from mercury arc to silicon rectifiers also meant that the ability to control the DC HV voltage was lost; at switch-on, the 11 kV DC supply was 'instant'. Phase-shift switching of the six or twelve excitrons in the power supply had allowed control of the DC voltage from full HV to $^5/_6$, $^1/_3$, $^2/_3$ or even $^5/_6$ of $^2/_3$ of the full HV value. This was useful in fault-finding or when prolonging a service until the scheduled end of transmission in the event of a minor fault. "Skimming the cream off" was one of the descriptive lines used.

The power smoothing circuits invariably contained chokes and capacitors and the reactive components would cause 'ringing' and exacerbated the peak current and voltage problem when silicon rectifiers were used.

Protection of the operator

Much has been written concerning safe working practice in broadcasters' corporate and local safety literature and a compilation, with co-operation from the engineers, was published by the British Standards Institution in 1978 as BS 3192 entitled British Standard Specification for Safety Requirements for Radio Transmitting Equipment **[1]**. By 1989, EU directives, *etc.* were incorporated and the BS reference was amended to BS 3192 - EN 60 215. The author was fortunate to have made personal notes from a 1990s presentation of the BBC version and the following is based on those notes.

It should be noted that the following descriptions and suggestions **do not cover all the possible safety issues** but are mentioned as a help to those operating and maintaining vintage and modern transmitting equipment. Readers will be able to tailor their actions in accordance with those referred to in the text. The author cannot accept any responsibility for omissions or errors and all information is given in good faith.

The principal hazards are high AC and DC voltages, RF voltages, heat, RF and X-ray radiation and the weight of the equipment. The risk to personal safety depends on the construction of the equipment (*e.g*. layout, interlocks), local protocols for safe working (*e.g*. disconnect from the mains supply before removing covers, handling of heavy objects) and personal risk assessment.

Low voltage high current supplies

It is generally accepted that AC and DC voltages below 50 V are considered 'low voltage' and are safe as far as voltage is concerned but it should be remembered that even single cell batteries, *e.g*. 1.2 V Ni-Cd and Ni-MH types, can deliver considerable short circuit current. In principle, a gold wedding ring connected across a 12 V lead-acid battery could heat up sufficiently to melt.

Figure 4 shows unshielded connections to a water-cooled filament rectifier. Staff were always aware that metal watch-bands and finger jewellery were to be kept away from such areas. **Figure 5** shows a similar area in the BD272 transmitter with the same hazard resulting from short circuiting of a low voltage high current source. Most of the copper braid of the 9 V, 325 A filament straps was covered (insulated), as were the filament posts, but **Figure 5** shows an often-visited enclosure, during wave changes, which exposed the technician to a hazard

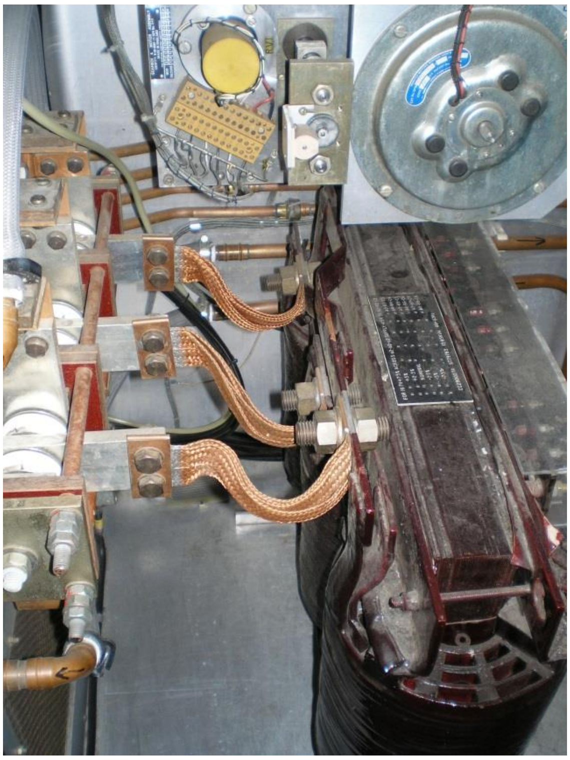

Figure 4. Unshielded connections to a water-cooled filament rectifier

Marconi (MWT/MCSL) and Pye TVT were unusual amongst the transmitter manufacturers because they allowed access to the equipment with the filament supplies on. Many others (Hans Plisch, AEG-Telefunken, BBC) configured the switching so that the unit was completely isolated before internal access could be gained.

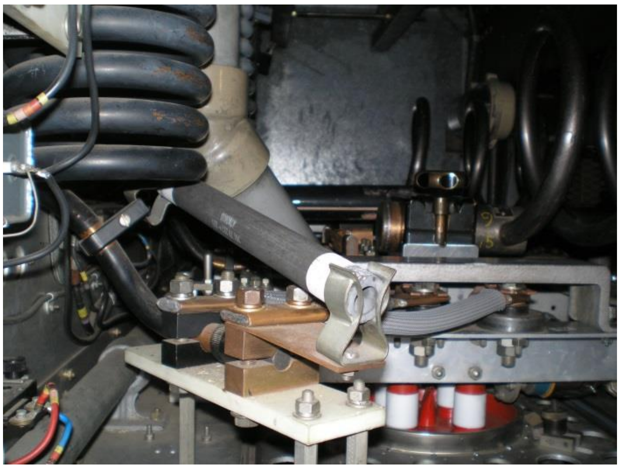

Figure 5. Shielding a low voltage-high current hazard in a BD272 transmitter

High voltage supplies

Terminals with connections above 50 V need to be shielded such that finger-contact, *etc.* is prevented and **Figure 6** shows a filament transformer on a MWT/MCSL 300 kW B6124 sender with the 415 V mains input suitably shielded in a transparent Perspex™ cover. Even with approved terminal strips of the 'chocolate block' variety, it is important to ensure that bare wires cannot touch the screw heads whilst working on the equipment and that the cable is fully inserted into the termination with no bare wire strands showing. The use of cable ferrules is recommended.

Figure 6. Filament transformer with Perspex shield

A strict protocol of ensuring that the charge on smoothing capacitors, *etc.* has decayed to a safe level before high voltage power supply and amplifier enclosures are accessed is essential. **Figure 7** shows the isolation and earthing switches, together with the access keys, for the BD272 transmitter. A further precaution to isolate the 11 kV DC feed from the rectifier to the sender was introduced and an additional HV DC switch was installed. This employed a wall-mounted, secure-cased, motor-driven DC isolator.

Figure 7. Isolation and earthing switches, together with the access keys, for the BD272 transmitter

The sender-mounted manual interlock was operated as follows to gain access to the sender-enclosure:

- The inner right hand handle was operated and a large rotary switch disconnected the mains supplies, *etc*. to the bias and auxiliary HT rectifier transformers.
- The outer DC isolator switch would be operated to sever the 11 kV DC feed.
- The earthing switch would be closed to apply substantial mechanical connections to a series of pillars to which the supplies were connected (**Figures 8, 9 and 10**). An inspection window was provided so that the operator could see the earths in place.
- The keys (Wilmott-Breedon 1960s car ignition types) could be released and removed and, after doing so, none of the switches could be operated as they were mechanically interlocked.

Figure 8. The pillar and earthing assembly inside the BD272 sender

Figure 9. Earthing switch implementation as used on a B6124 300 kW sender

Figure 10. Substantial connection terminals near to the earthing mechanism

When used to open a sender door, the key was held captive in the lock mechanism so that it could not be replaced in the isolator assembly by accident and the sender repowered with a door open. Documented, regular checks were made to ensure total integrity of the electrical/mechanical interlock system. A key-switched control voltage (50 VDC) interlock to prevent a high power broadcast transmitter from powering was employed at a certain HF site and it was found that the switching had failed and that the ‘OK-to-power’ interlock was still present when the staff thought it was safe to work on an antenna. After that thankful near-miss, the procedure was altered immediately and all the transmitters on site were taken to the fully switched-off and earthed condition with their interlock keys removed, locked away and signed for, during the work. Other sites with the same equipment were told of the failure and the consequent revised procedure.

Micro-switches can sometimes be convenient as safety interlocks and are commonly used to interlock a removed panel from HV equipment by interrupting a control supply or even mains voltage. Door-operated micro-switches are another form of interlock but it is important to be aware that micro-switches can be fairly delicate devices and could fail ‘not-safe’. Such interlocks are also occasionally found on vintage valve equipment, a good example being the TCS transmitter, whereby removal of the transmitter unit from its case trips a switch in the rear of the unit, removing the mains supply to the PSU. Unfortunately, in amateur radio circles, there has been a tendency to short out this switch to facilitate servicing of equipment and those in possession of equipment with interlocks should ensure that they are suitably enabled.

If any reader owns equipment with HV isolation and earthing (even if simple or on a small scale), it is prudent to have an inspection regime in place to provide regular checks on the effectiveness of the system. Such a mechanical isolation and earthing system is suggested as essential for supplies over 1000 VDC. To avoid confusion, the term ‘earthing’ refers to the DC-return of any current-carrying circuit. This may be the metal chassis, provided that the circuit is not isolated from the chassis. The reader is advised strongly to check the wiring of the specific item of equipment to identify the appropriate discharge paths. It is not advisable to interpret ‘earthing’ as grounding to the real earth because, even in a well-grounded system, significant earth resistance could influence discharge rates.

An earthing wand (**Figure 11**) is a worthwhile investment and should be provided. Such a wand comprises an insulated handle with a metal hook connected to chassis/earth by a length of flexible wire of adequate cross-sectional area. The connection between the hook and the wire should be visible; if the wire is insulated, the covering should be transparent and the termination to the chassis should be visible and reliable. Earthing wands are only for use on DC circuits.

If amateur equipment does not employ a comprehensive isolation system to ensure the HV circuits are dead for access, an alternative approach has been to place several series-connected high value discharge resistors across HV circuits. It is strongly advised that a strict regime is adopted to ensure that the resistors are continuous and of the correct value.

Grounding of modularised assemblies

Modularised assemblies present specific challenges with regard to earthing as explained previously by the author **[3]**. It is not recommended to rely on the mechanical fixings of the modular chassis and case to be the earth electrical connection. It is important to install safety earth connections, using wire capable of carrying the full fault current and suitably insulated, between the chassis sections and casings. The links must be secured in such a way that good reliable contacts are made and the fastening hardware does not come loose due to vibration, *etc*. Safety earths should not be used for any other purpose (such as a restraint for a hinged panel).

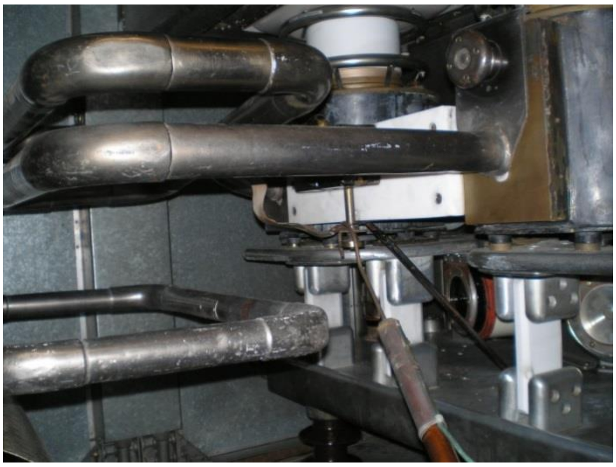

Figure 11. An earthing wand in use on the centre tap connection of the 11 kV modulated feed to the final RF amplifier in a BD272 sender

If modular mounting of equipment in a rack is envisaged, it is recommended that each piece of equipment has a separate earth wire attached securely to the chassis and bonded to a common point. From that same point, a separate earth wire is taken to the mains distribution terminal so that, in the event of a cordage/connector problem, the chassis remains earthed. The hardware fixing the earth tags should be nuts and bolts, tightened with tools rather than hand operated wing or knurled nuts. The cross-sectional area of the earth wire needs to be sufficient to carry any fault currents possible.

It should be appreciated that most amateur ‘vintage’ installations are modular, with a variety of interconnected units which need to be grounded accordingly.

Fusing of supplies

Fuses protect both the operator and equipment and are essential components in any equipment powered by electricity no matter what voltage. However, for maximum protection of the operator, it is important that fuses in mains and HT circuits be wired correctly. Hence, for 32 mm (1.25 inch) and 20 mm panel-mounted fuse holders, the *incoming* supply should be connected to the tag furthest from the chassis whereas the tag on the side of the fuse holder should be wired as the *outgoing* supply. This is done so that, in the event of the fuse carrier and associated fuse being held in the fingers after a replacement fuse has been fitted, insertion of the carrier and subsequent connection to the side contact does not result in a shock. In a recent article, Bronek Wedzicha M0DAF **[4]** quotes Peter Chadwick as follows: “Although normal 1.25 inch fuses have been used at 750 V in certain military equipment (even though only rated for 250 V), it is rather dangerous practice and even more so for smaller-size fuses. The problem is that the explosion, when they burn out with a large amount of energy, can coat the inside of the fuse glass tube with copper and so the circuit does not open. For HV fuses, I use a length of 44 SWG wire between two ceramic stand-offs about 3 inches apart; 1.5 inches would suffice at the lower voltages encountered in 1500 V supplies. Such fuses are much safer when they do blow. Even ceramic fuses, filled with anti-rupture powder, do not stand up well to these voltages which are far in excess of those for which they were designed”. Bronek’s article included a 1500 V PSU and, in keeping with Peter Chadwick’s suggestion, the fusing arrangement adopted is shown in **Figure 12**.

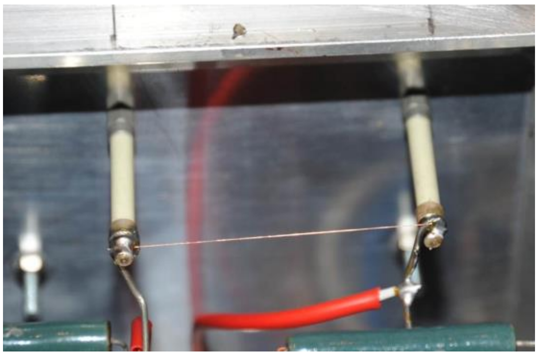

Figure 12. A high voltage fuse made by connecting fuse-wire between two 1 inch ceramic stand-off insulators 2 inches apart

Mains wiring

The use of IEC mains connectors in chassis and flying lead formats is to be preferred and certain old-style types (*e.g*. Bulgin Bakelite three pin and Neutrik XLR mains types) phased out. The use of cable anchorages, either *via* grommetted holes with plastic P-clips or by through-chassis clamps, is recommended.

In the UK, the neutral side of the mains entering equipment is not fused, there being fusing only on the live side of the mains. Some vintage equipment may still have fusing on both sides and consideration may be given to bypassing the fuse in the neutral lead. In some countries on the Continent, dual fusing is permitted. It is also good practice to label the fuse rating and type to be used (mains, quick-blow, anti-surge, *etc.*) on the panel next to the holder. It is sometimes tempting to use mains cordage with the brown-blue-green/yellow coding for internal connections *within* apparatus for supplies other than mains. A possible danger/risk is that, at a later date when fault-finding, *etc*. it is found that the green/yellow wire was actually used for a supply voltage rather than the usual, expected, earth connection. The author has seen the use of this cordage in a MWT B6029 10 kW MF transmitter as the original equipment manufacturer’s three phase AC (delta) feed for the air-cooling fan motor; needless to say, it was quickly changed to the correct colour-coded cabling.

Readers are reminded of current practice, as recommended in the ‘Foundation Licence Now!’ training book **[2]** published by the RSGB, concerning shack AC supplies. Newcomers are taught that, if possible, a single switch, ideally one with a RCD, is available in the shack **to isolate all the supplies to the technical equipment** and that other members of the household, *etc*. are made aware of this switch and know to operate it in the event of a fault. Also taught is that, in the event of an electric shock incident, the person suffering is not touched until the supply has been switched off as they may still be in contact with live mains. If so, the rescuer could also receive a shock.

Static build-up

Certain antenna combinations can result in static build-up on ATUs and a suitable discharge path (often an RF choke or a 100 kΩ–1 MΩ resistor between the antenna terminal and earth) can be added in the transmitter and ATU. **Figure 12** shows the 30 μH 'static leak' on one leg of the balanced feeder on a BD272 sender. As well as the actual electric shock risk there is also the possibility of the initial shock causing a physical reaction leading to a more serious incident.

Figure 12. A 30 μH 'static leak' on one leg of the balanced feeder on a BD272 sender

Skin burns

Those readers who operate valved transmitting equipment, even at modest power levels, do not need to be reminded that valves produce significant amounts of heat. Indeed, It is not unknown for anodes to glow red in some fault conditions or when very high duty amplitude modulation is applied continuously, *e.g*. single tone or two tone modulation tests. Common sense dictates that one avoids contact with such hot surfaces, but metal-work in the vicinity of valves may retain heat for longer.

Arguably, the greater hazard arises from presence of RF at high voltage on exposed terminals, as might be found on WWII or other vintage transmitting equipment, or on aerial wires. David Smith G8IDL **[5]** illustrates well the reasons why a short HF antenna may have a high RF potential at its base, but this is true generally of feeds to non-resonant antenna systems at some frequencies or at the far ends of resonant dipoles. At low power levels, the result of coming in to contact with such a conductor is to suffer burns to the skin, accompanied by the smell of burning flesh and resulting in painful white blisters. At the other extreme, David Smith **[5]** warns that the encounter can be lethal.

High temperature and fire

It is important to ensure that adequate ventilation is provided within enclosures so that excessive temperature rise is prevented. If there is a large variation expected, cabling and components specified to cope with the variation are essential. If forced-air cooling is employed, monitoring of the fan operation is recommended, *e.g.* by use of a flap switch. If natural cooling is used, *e.g*. for a solid-state amplifier, a fault can lead to an increase in temperature possibly leading to consequential failure, *e.g*. transformer fire. A thermal overload device bolted on to the heatsink may be used to trip the power supply.

If a feed-through connection is required, particularly if it is to carry a high current which could be AC, DC or RF, it is important to ensure that the electrical connections are not reliant upon pressure on to an insulating material as, over time, the material can shrink and the connection will become loose. For RF, steel hardware should not be employed, brass being preferred. Otherwise, localised hot-spots can occur even when running the permitted amateur power outputs. The effect can be exacerbated in certain ATU circuit configurations where high circulating currents are generated.

Figure 13 shows a mains transformer with the recommended way of connecting to a high current point with lock nuts and spacing from the SRBP plate on the right hand terminal. The left hand terminal shows a connection where continued pressure is reliant on the SRBP not compressing over time and is not recommended.

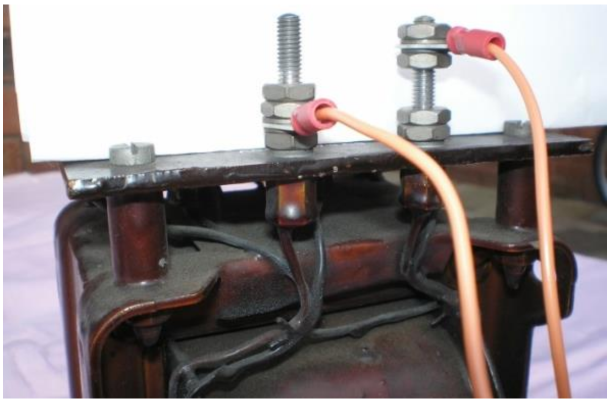

Figure 13. Mains transformer with (on the right hand side) the recommended way of connecting to a high current point

Flame retardant insulation on certain components and cabling is advised if the risk of a fire is possible in high-powered apparatus. Low smoke and fume (LSF) cable is available to the same electrical specifications as regular cable. It is also important to have both a carbon dioxide and a powder fire extinguisher in the shack.

Harmful radiation

RF enclosures should be screened for reasons of personal safety from radiation and to prevent interference to local communications equipment. VHF, UHF and particularly SHF frequencies can be more dangerous than LF, MF and HF.

Miscellaneous hazards

This completes the recommendations from the British Standards Institution however, for completeness, a short appendix is given below with additional general points

When working on chassis and equipment sharp edges on metal pressings, fixing hardware, *etc*. can provide an expected hazard. When fabricating metal, it is important that burrs and swarf are removed from the area of work and eye protection worn when filing, sawing and using power drills, *etc*.

Transformers can be heavy and one often has to extract them from tight spaces. Heavy-lifting protocols apply equally to such objects as to the lifting of weighty equipment.

Headphones can help with reception of weak stations but a high volume setting or burst of static can damage your hearing **[2]**.

Take care with antenna rigging, ladder climbing and roof work **[2]**.

Overall

Stay safe and enjoy the hobby, remember though;

- death is permanent
- “it’s the volts that jolts and the mills that kills”.

References

1. British Standards Institution BS 3192 / EN 60 215. *British Standard Specification for Safety Requirements for Radio Transmitting Equipment*. Latest issue (1998) available as a PDF at £146 from http://www.bsigroup.com/
2. A. Betts G0HIQ. *Foundation Licence Now!* RSGB. ISBN 9781-8723-0980-4, 5th edition, pp 28-29
3. D. Porter G4OYX. 60 m from the M54. *Signal*, 2013, 27 (May), 3-12.
4. B Wedzicha M0DAF. A series modulator for AM. *Signal*, 2013, 26 (January), 3-11.
5. D Smith G8IDL. Using a short vertical antenna at HF. *Signal*, 2013, 29 (November), 14.

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