T500M 12V 500W HF Linear

By G8MNY (Updated Nov 21)
(8 Bit ASCII graphics use code page 437 or 850, Terminal Font)

A few years ago I bought an old large commercial Trans World Electronics Inc, 12V HF Amp, for "MEDIUM POWER Air/Ship/Army" use, at a local ham junk sale. (actually used in BBC Engineering Vans, & cost around £2000 in 1977). Zane M1BFI says they are also badged as Metron & AEL.

```
       ///////////////////////│  2-30MHz, 4x 150W push pull amps in parallel.
      /////////////////////// │  > 10dB gain, 70W max drive. (typical 15-40W)
     ///////////////////////  /│  IMD 3rd Order >-32dB @-500W, >-36dB @ 400W.
    ///////////////////////  / │  PA harmonics to better than -43dB.
   ///////////////////////  /  │  13.6V @ 75 Amps needed for full 600W output!
  ///////////////////////  /  /   1kW DC input, Infinite SWR rated, <2:1 recom.
 ││││││││││││││││││││││││ /  /    15A charger & car battery will power it (SSB).
┌────────────────────────┐   /    Thermal 70°C heatsink shutdown. CW/SSB use!
│T500M     __     ____   │  /     Over current 75A trip (high SWR & over drive).
│  o<-    [__]   [____]  │ /      Manual & Remote operation (On & Band select).
└────────────────────────┘        Weight 8kg.
```

It was cheap as it had a fault, it came with the handbook, so I expected a problem or two. On examination it basically worked OK "no blown amps", but it had a faulty band switch. That was just a "light contact" on the single wafer switch, causing non operation, or no "band filter relays selected" (no RF output path!) & easily fixed by bending contact once the switch was stripped down.

S C H E M A T I C

```
                               Rx & through path
   Drive┌────────────────────────────────────────────────────────────┐Ant
RIG____/│   ┌─────┐50Û┌────────┐       ┌────────┐50Û     ┌──────┐    │\___ANT
       │└───│Atten│───│Splitter│       │Combiner│────┬─/─│Filter│─\─┬┘│
       │ 70W└─────┘30W└─┬─┬─┬─┬┘ ┌───┐ └┬─┬─┬─┬─┘600W│ │ └──────┘ │ │ │ptt
       │ Max       Max  │ │ │ └──│PA1│──┘ │ │ │      │   ┌──────┐   │
       │                │ │ │200Û└───┘200Û│ │ │      ├─/─│Filter│─\─┤
       │                │ │ │    ┌───┐    │ │ │      │ │ └──────┘ │ │
PTT>───┘ Drive ┌────┐   │ │└────│PA2│────┘ │ │      │   ┌──────┐   │
             /─│Bias│─> │ │  200Û└───┘200Û  │ │      ├─/─│Filter│─\─┤
             │ └────┘   │ │      ┌───┐      │ │      │ │ └──────┘ │ │
     Trip  DC│          │ └──────│PA3│──────┘ │      │   ┌──────┐   │
     ┌──┐  ON│          │    200Û└───┘200Û    │      ├─/─│Filter│─\─┤
12V__│/_│__/ └─>        │        ┌───┐        │      │ │ └──────┘ │ │
     └──┘  │            └────────│PA4│────────┘      │   ┌──────┐   │
           │                 200Û└───┘200Û           └─/─│Filter│─\─┘
Band Switch│                                           │ └──────┘ │
or Remote>  ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

L A Y O U T (Bottom cover off)

```
  ┌───────────────────────────────────────────────────────────────┐
  │ ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──│ SO239
 Ì│~~~~~──  Pot            PushPull   |                          │  Rig
 ¦│100   │ Bias        =()=┤▒▒▒▒│Output  │Relay│ >15MHz Filter│Relay│
 ¦│Amp   │Circuit   [▒] PA1 Transformers  ~~~~~              ~~~~~
 Ì│Meter │          [▒] =()=┤▒▒▒▒│     |
  ├------~~5R [▒]Input                  │Relay│8-15MHz Filter│Relay│   ▐█ 13.6V
  │           [▒]Spliter=()=┤▒▒▒▒│   |   ~~~~~              ~~~~~ /  +▀  DC 75A
  │──────.    [▒]    [▒] PA2                                       ¦  -▄  Wing
  │75A DC  ├──[▒]    [▒] =()=┤▒▒▒▒│ │ DC │ │Relay│ 5-8MHz Filter│Relay│█  ▐█ Nuts
 Ì│TRIP &  ├()shunt██████████████████Relay  ████████████████████████
 /│ON/OFF  │__▄████      =()=┤▒▒▒▒│ └────┘                           12 Way
 █ã======' PushPull[▒] PA3          |  │Relay│ 3-5MHz Filter│Relay│ │ Jones
  │Drive│    Driver[▒] =()=┤▒▒▒▒│  [▒▒]Output~~~              ~~~~~ │ Socket
  │Relay│   Transformers            [▒▒]Combiner┐
  │~~~~~               =()=┤▒▒▒▒│  [▒▒]│ │Relay│ 2-3MHz Filter│Relay│
  │| ThermSw      [▒] PA4            [▒▒]   ~~~~~                    SO239
 █│|Band          [▒] =()=┤▒▒▒▒│        |                │ Ant │     Ant
  │|Switch     P.A. PCB          :RF lead:     FILTER PCB │Relay│
  │ ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──  ──~~──│
  └───────────────────────────────────────────────────────────────┘
Front                                                              Rear
```

PA protection is from a 75A fast magnetic trip for bad SWR & over drive, it has an external calibrated shunt, & a thermal 70°C auto resetting cut off switch. The 100A ammeter uses 10cm of the thick DC lead as its calibrated shunt.

The bias supply is a simple 2 transistor thermally tracked circuit that provides up to 2.2A of current @ 0.69V, for the 4 class AB push pull amps. Excluding other currents, total PA quiescent current should be 1.6-2A, (which gives the best two tone linearity results at around that level. See 5/)

P A R A L L E L   A M P S

Four identical push pull Amps (>150W/Amp) use 2x PT9847 100W HF transistors with large very well rated input & output matching transformers (no saturating IMD products!) consisting of 3 & 5 ferrite rings stacked on each of the 2 brass tubes for the 1 turn low Z side of the 5:1 turns ratio. The smaller 2x 3 ring transformers are used for the driver & much larger 2x 5 ring ones for the outputs. A large amount of RF NFB (for good linearity) is provided by 47Û 5W & u1 C between each collector & base of the 8 transistors.

```
      ONE of 4 PA AMPS                    Input & Output Transformers use...
         NFB┌─47─┐         1:5          I/P 3 rings/side, O/P 5 rings/side
200Û 5:1   u1===   ├─────┬────┐  ______  Collector───┤▒ ▒ ▒ ▒ ▒├+PCB
─────┐ ┌─────────┤< e   │    ││( 200Û   or Base  tube~~~~~~~~~~~~~~tube
5W 5 )││          ┴   │1n2 _)│( 5 Turn         /////               \\\\\
Turn )│(__  NFB     ===    │ )│( Output   5 turns|||||│▒ ▒ ▒ ▒ ▒│ |||||
Input)│(  │ u1┌─47─┐    │  │ ││( >150W      for |||||          ├+|||||
     )││  │  ===   ├────┴──)─┘│(          200Û |||||│▒ ▒ ▒ ▒ ▒│ |||||
     )│└──)───┴───┤<PT9847 │   ┴           ====\\\\\~~~~~~~~~~~~~~/////
     ┴     ├bias    │e     ├────┬──────+12V        tube               tube
.6V @.7A ===2u2     │     u1=== ===1mF @18A   Collector───┤▒ ▒ ▒ ▒ ▒├+PCB
───────────┴────────┴────────┴────┴─────     or Base    Ferrite ring stack
```

The inputs & outputs are wired up from the drive splitter & output combiner with staggered wire lead lengths, so all the RF signals ends up exactly in phase.

```
       ┌──────>PA1>───────────────┐
       (|_100R_            _100R_|)
      _(|  1W  | 200Û     |  5W  |)_
     | (|_100R_| AMPS     |_100R_|) |
     | (|  1W  |          |  5W  |) |
 50Û | └───────)─>PA2>────)──────┘  | 50Û
Drive>┤SPLITTER |          | COMBINER├>O/P
 25W | ┌───────)────>PA3>─)──────┐  | 600W
     | (|_100R_|          |_100R_|) |
     |_(|  1W  |     200Û |  5W  |)_|
       (|_100R_|     AMPS |_100R_|)
       (|  1W                5W  |)
       └────────────────>PA4>────┘
```

Splitter & combiner both have out of balance dump 100R to soak up any amp differences, for best stability & linearity. Ferrite ring & tube construction like the transformers.

```
 ┌───────────┬─────┬───────────┐
100Û     100Û  100Û     100Û 1 or
 │  ___ ___  │     │  ___ ___  │  5W
 │ |___X___| │     │ |___X___| │
▒│|│▒    ▒│|│▒   ▒│|│▒    ▒│|│▒
▒│|│▒    ▒│|│▒   ▒│|│▒    ▒│|│▒
~~|~~~~~~~|~~~~~~|~~~~~~~|~~\Drive/
 PA1      PA2     PA3      PA4  Output
```

F I L T E R S
There are 10 relays that in pairs, switch in 1 of 5 QRO 2 section (30dB/O) Pi low pass band filters, & reduce the quite high PA harmonics to >-43dBc.
N.B. there is no PA RF output path, without a pair of band relays operated!

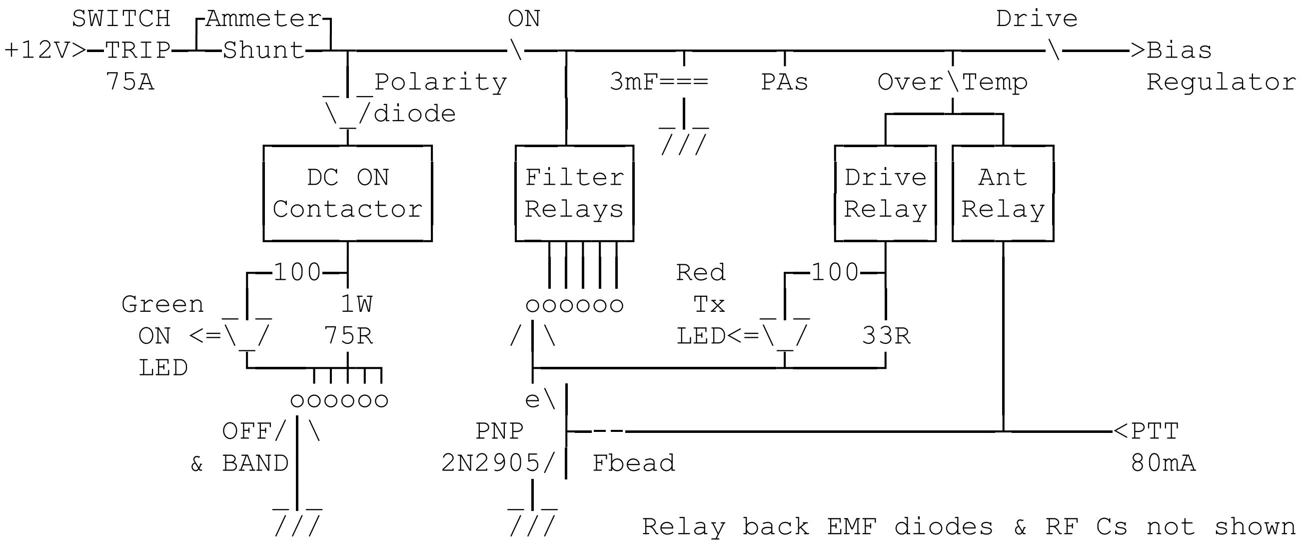
```
      Filter In             Filter Out
  ______Relay                 Relay______
 From   /o─┬──())))──┬──())))──┬─o\   To
Combiner|  │    L    │    L    │ |  Aerial
        | ===       ===       === |  Relay
        |  │C1       │C2    C3│  |
  ______|__│_________│________│__|______
```

Band	C1/C3	C2
2-3MHz	390+430p	750+680+270p
3-5MHz	390+120p	750+270p
5-8MHz	270+47p	430+200p
8-15MHz	82+82p	200+150p
15-30MHz	82p	56+120p

The Ls are wound 2cm ferrite rings, or air for the highest range. The Cs are all 2-3kV RF types. Using several Cs in parallel not only gets the odd filter values needed, but also gives greater current handling, reduced lead inductance & swamps any self C resonances. The 4 unused filters get shorted to ground.

H E A T S I N K
At 25°C ambient in free air, the very large heatsink does not need a fan on 30% duty SSB Tx cycle, despite only the front part getting quite hot. But carrier modes are to be avoided (input attenuator overheats on lower bands!) or the temperature might rise above the heatsink thermal 70°C auto resetting trip.

M O D I F I C A T I O N S
1/ LED INDICATORS, REDUCED STANDBY CURRENT, & GIVE RELAY SEQUENCING.
Rx mode current was quite high (band relays), I found all the relays would operate OK down to 7V. So I added series Rs to reduce the currents by 25% for the slow to operate ones, & I used the R's added voltage drop to light 2 status LEDs too.



Relay back EMF diodes & RF Cs not shown

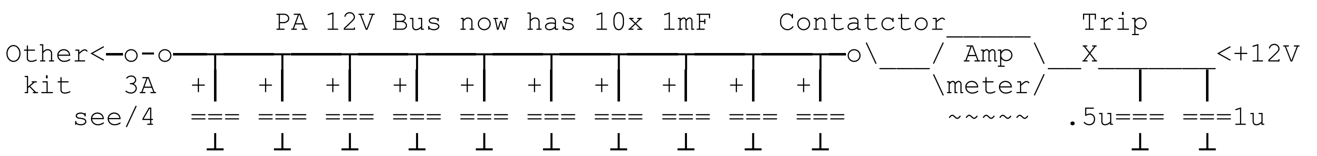
Added components mounted on or near the band switch.

Input & output filter relays (not in Rx path) are now only operated when the PTT is active, from the added PNP emitter follower. The drive relay also puts on the PA Bias, & is last to operate with a series LED too is also buffered. But the Ant relay must be faster, so it is left directly on the PTT line!

These modifications save 160mA on standby & helps keeps the filter relay contacts clean! It also reduces the PTT current from 250 to 80mA (limited PTT current on my exciter's reed relay). And the slight voltage differences on identical relays, is all that is needed to ensure the relays all operate in the right sequence order Aerial, Band, & last Drive/Bias relay, so no QRO RF contact splats.

2/ RIPPLE SMOOTHING & RF on DC LEADS

Only 3x 1000uF was fitted on my PA's +12V rail, the diagram showed 3x 2200uF, & having a large bag of similar 1000uF caps, I added 7 more symmetrically stacked up around the 4 amplifiers to give 10,000uF in all. Much more than that, might weld up the DC contactor! Each of these Caps can give a few amps at audio, reducing some of the battery lead AF ripple current.



To stop RF on the DC leads (don't want any in the shack), I also added a 1uF non electrolytic internally across the DC terminals, & another 0.5uF from +12V to the nearby "RF In" SO239 ground.

3/ DC LOSSES

This QRO amplifier has very high currents, & a drop of 1V = 100W less peak RF power! DC lead losses, & the use of unsoldered crimp connectors all adds up. So with the amplifier into a dummy load, I use a DVM on 2V range from battery -ve & then the +ve to highlight where the voltage was being lost... drops on the leads, contactor, & tags. (If RF gets up your meter use 1k R in series as RF stopper at probe end.)

Metal case connection of the -ve terminal had not been used, it could reduce the internal earth wire loss to near zero. It was just bolted on the painted panel. So I ground off the paint around the earth post, greased the bare aluminium to keep the air away, & bolted it up tightly. I did the same to back panel to heatsink screws with lock washers etc.

External DC cables, I use short heavy leads to a 75A SMPSU, or "starting grade cables" to a large battery, or 30A leads to a small 24AH battery & a 30A PSU. See "battery leads" below.

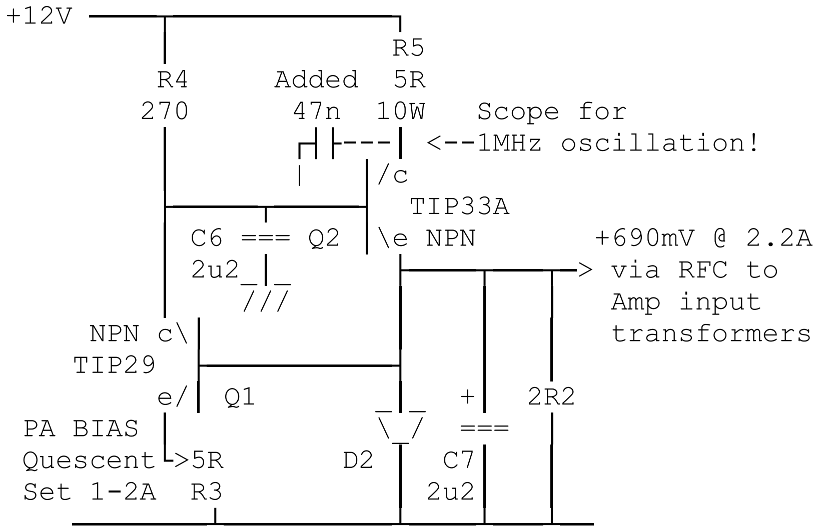
4/ DC FUSE

There was no low current fuse! So I soldered in a 3A one in the small wiring feed (to the band switch) to reduce the risk of an internal fire!

5/ BIAS

R4 turns on Q2, when Q2 emitter > 0.6V, Q1 turns on reducing Q2 base drive. Value of R3 is used to set the exact bias voltage, R4 & supply voltage also affect the bias slightly. R5 limits the max current, D2 is a safety feature. Q1 & D2 are thermally connected to the PA (on the same heatsink).

PTT Switched (from Drive relay)



This circuit was slightly unstable when scoping R5 (5R), so I added a small capacitor base to collector on the large NPN to stop it.

Components were not the same as original diagram!

6/ ALC

There is no ALC system on this AMP, & I am used to an old Valve amp with a power front panel ALC control. With PA ALC, the driver power is automatically set to the wanted level, & with the PA turned off you are back to full bare foot power. So I designed this ALC circuit for this PA...

```
+12V Tx>─┬────────┬────────────────────────────┐
         R4       5R                           │
        270  PA  10W                          15K
         └─>Bias<─┴──270──┐   2n2              │
           Circuit        ├───┤├┐              │      Front panel
                        e\│     │             10K     between Trip & Meter
             2N3703 PNP   │─────┴──>POWER           50W-600W
        mounted on POT/   │                   POT     ALC Control
                   ┌──────┘                   _│_
                  4K7    │ │ |                ///
                   │      Fbead                    Mounted on 12 way JONES plug
Input             -ve│                        Fbeed                 spare Pin
RF on >─1K──┤<├─┤<├─┤       └──────────────────────---┤<├──┬──────┬───>ALC to rig
Drive        1N4148  │-20V     long wire       1N4148  │    100    0V to -10V
Atten               ===      with DC leads              │     │ -
                 2n2│                                 4K7   === 4u7
                    _│_                                _│_   _│_+20V
                    ///                                ///   ///
```

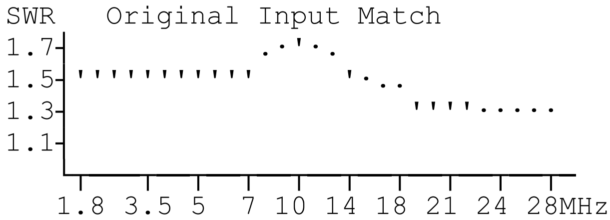
The -ve supply for the ALC is derived from the RF on the attenuator after the DRIVE relay. The -ve after the 4K7 it is normally clamped to +ve by the PNP. But when the PA bias current (limited to 2.2A by 10W 5R) reaching the 8 PA bases, gives a voltage lower than that set on POWER POT, the clamping stops, letting the -ve through. The series 1N4148 diode & 4K7 load, ensures only -ve voltages are given to the exciter to reduce power drive. The 4K7, 4u7 & 100R give a sensible ALC time constant action.

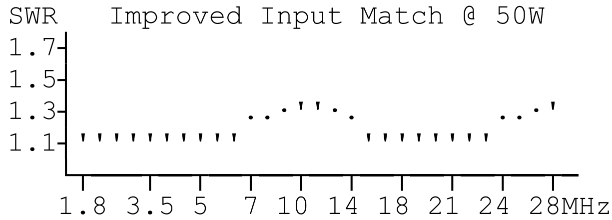
MY CLEVER ALC DESIGN!

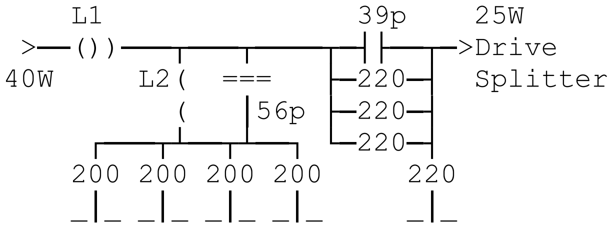
The ALC works very well compared with manually keeping the drive power always low enough at all times, so the PA never clips. By using bias current demand, it is quite effective at keeping the PA operating in it's linear region, by reducing the driver power in time. This is down to the large amount of NFB used in this commercial PA, that increases the PA's drive power, as the amp gain falls off at full power. This sudden increase in bias current, occurs just before the PA actually hard clips. So a useful & accurate maximum drive threshold point, that caters for SWR, supply voltage, or Rig power setting.

7/ INPUT SWR

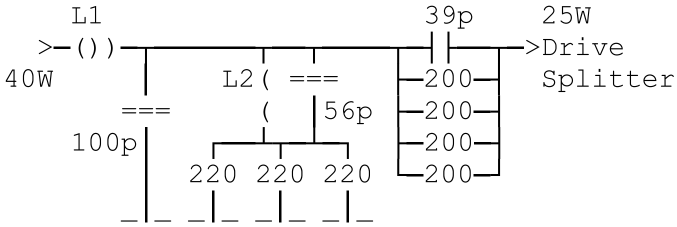
The input frequency compensating attenuator circuit was not as the diagram & the SWR was not all that good, despite all components testing out OK.







Actual Circuit



New Circuit

There was a bump @ 10MHz & that is from the drive splitter load. L2 & 56pF disconnects the added load, as the 39pF bypasses the series attenuator Rs on the higher frequencies, to flatten the amp gain. The original diagram did not have 220R to ground, but had 20pF to ground @ the L1/2 junction. I found making this a 100pF (Tx grade) was better on 10m band & changing the load Rs around gave a better lower band input match.

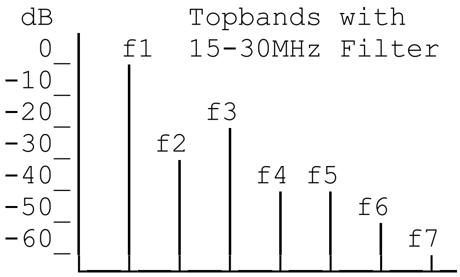
Flat gain is less important than driver rig linearity, due to poor load. The input SWR will change with drive level (higher Z at more power), as the RF NFB level reduces, correcting each amplifier gain, as each amplifier works harder.

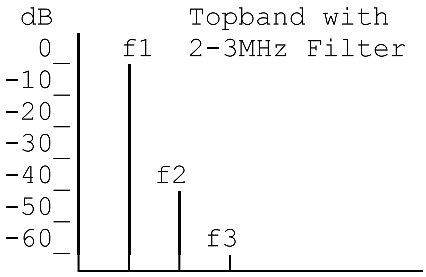
T E S T I N G

At a club meeting, 2 of these amplifiers (modified & unmodified) were tested with 2 tone linearity test & with a spectrum analyser for harmonics. Both amps performed well up to the sudden (like AF Amps) 600W hard clipping level. This was due to the effective NFB keeping good linearity until it fails. But even brief full carrier testing on lower bands did provide smoke from the underrated input attenuator!

The 2 tone test showed very good linearity to 400W PEP, so I think the quoted IMD figures look right. On air tests with SDR displays show the amp is very clean & no other sidebands/spatter could be detected @ S9+30dB etc.

The harmonics tests on a spectrum analyser showed the need to have the "right" low pass filter selected, as these un-tuned broadband amps are quite harmonic rich otherwise!





On Topband the 2-3MHz LPF is not really that good for the 2nd harmonic! Higher bands fared better with filter performance. Of course no problem at all after a good ATU.

On actual testing into aerial via a high Q QRO ATU, I found it was possible to get slight PA parasitic oscillation (of the RF envelope) at very high power. It never did this into my dummy load or an actual aerial on Spectrum Analyser! But with the final tweak to the input attenuator, it tested OK across all bands, with ATU tuning over a range of SWRs. So sudden high SWR in a T tuner might be indicating a Tx PA "parasitic" or tuner/aerial "arcing"!

H A Z A R D S

Current Loops:
Although 12V is fairly safe (compared to 230V or 3kV), with high currents anything metal is a hazard! This includes the PL259 plug & mains earth wiring! I put heat shrink sleeving on 259 plug rig lead near the +12V terminal. Care must be taken to ensure the "75A" does not flow around unsuitable leads in parallel e.g. Mains PSU IEC lead earths & Rig power leads!

Battery leads:
With single battery, use short "starter gauge" cables, with soldered on copper tabs/lugs, made from thin Copper sheet 0.5mm, wound on a 8mm drill 1.5 turns. Then flatten one end, solder to cable (on cooker).

```
             __________ heat shrink
  Drilled    ___  ____________
  Hole ____/    |~STARTER CABLE
       ~~~~_____|~____________

          ~~~~~~~~~~~~
```

Clean up & apply heat shrink sleeve or tape. Drill hole for PA & battery connections. Mark up + & - with coloured tape. Apply water/acid repellent grease to tabs, bolt tread, washers etc.

Lead Acid Batteries:
Other than high current & fire hazard of melted leads, batteries have Sulphuric Acid that always seems to get out & damage clothes etc, you can replace clothes but eyes are something else! Take care!

H2 Anti Explosion Tip:
Always "blow" at the battery, before making/unmaking connections, this "simple action" reduces the chance of hydrogen being around for sparks to ignite!

High Power RF:
At these powers RF leakage from loose PL259, high Filter & Aerial voltages are dangerous! Double check connectors & everything is SAFE before keying up, & RF testing is essential. Otherwise you will soon learn about deep RF burns & gain "Respect for the RF" the hard way!

RF Chokes:
Wind coax or balanced aerial leads, to make "RF chokes" near shack end, this helps keep shack RF fields & RF lead currents down!

I N U S E

Running it /P for 8 days at a summer camps on HF with autocaller & plenty of pile ups, I did find a fan system was useful, to cool the front part of the PA (used a small Germanium transistor to sense temp & a high gain Tip Silicon to operate fans in series.)

A 25A linear PSU floating batteries worked well. The rig was floated on another battery & PSU. This did allow a much smaller petrol generator (650W 2 stoke) to be used rather than a 2.3kW 4 stroke & QRO Valve Amp. (That was used for cold night to keep the operating tent warm!)

In my shack I now use a DEL 13.8V 75A SMPSU with thick short leads to the PA.

Reports were all pritty fantastic, good clear comms quality AF from the old IC735 with its hard AF clipper mic processor, 2.4kHz SSB filter, & a strong signal. A local looked at the remote Hack Green SDR website radio, only to comment "my /P station much was stronger than he was & it was narrower!"

LOW POWER FAULT

After many years of use, I noticed only 350W peak output & lower DC current drawn occasionally. Investing all the Rs were OK, & the combiner balancing 5W 100Rs were getting quite hot. Scoping each of the 8 transistor bases showed the RH output PA4 pair was different. Removing the NFB on this pair & a little RF drive I notice a spark on the 8th collector. It had developed a difficult to see crack in the solder joint. Resoldering fixed this OK, & I was very lucky it did not need a replacement old transisor. This fault has occured twice now on the other end of the row of PA transistors, where there is maximum thermal expansion stress on large PCBs, with bolted down bits & loads of heat cycles, or /M & /P kit!

See my Tech buls on "AF 2 Tone Test Osc Design", "Transistor PA Biasing", "Lead Acid Batteries", "Variable Speed Thermal Fan", "DEL A870P7 SMPSU 12V 70A", "12V 75A Del SMPSU Mods", "2nd Car Battery for /M & /P", "Rig DC Power & RF Hazards", "Using 2 HF PAs" & "NORTHERN 650W 2 Stroke Genny".

Why Don't U send an interesting bul?

73 de John, G8MNY @ GB7CIP