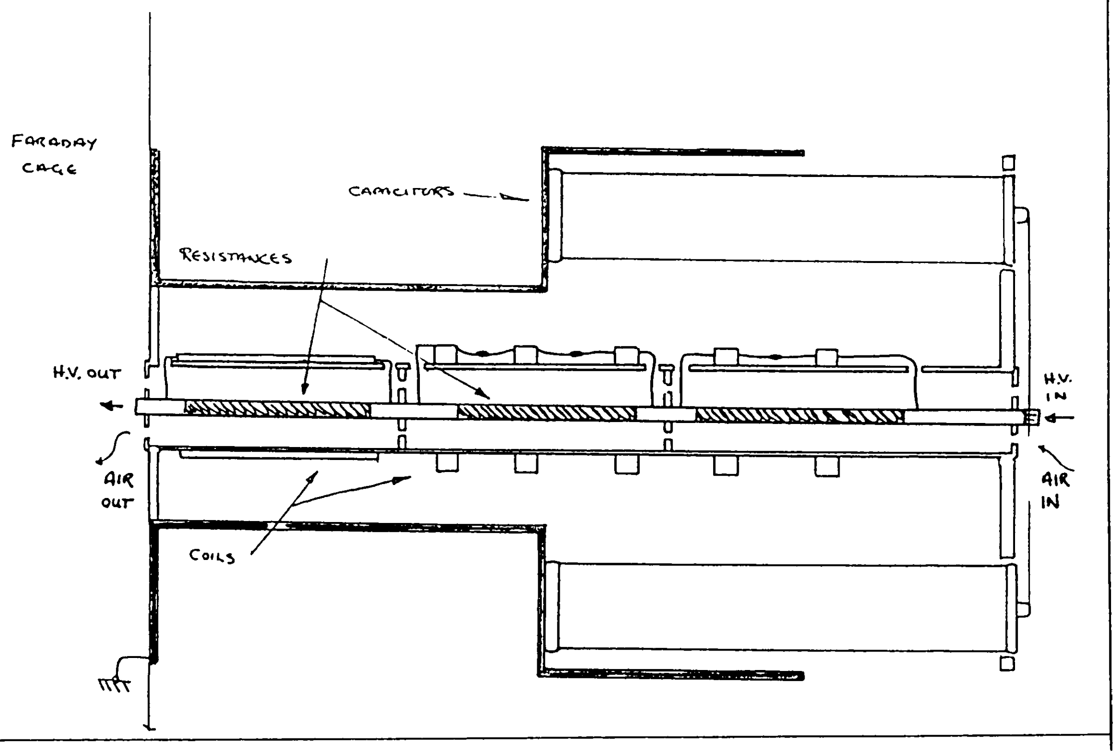
17 April 1990 Note PS/LP 90 – 20

COOLING FOR THE LIL MODULATORS HV FILTERS

S.C. Hutchins

After the discovery of broken and burnt resistors in several HV filters an investigation has been made to investigate the air cooling needs for the HT filters of the lil modulators. Although the cause of the damage seems to be due to the resistor end connections, improved air cooling is felt to be necessary. The function of the filter is to slow down the fast negative wavefront generated by the Thyratron switching action, to prevent damage to the charging diodes and other components in the charging power supply.

Figure 1: Section through the HT filter



The filter is a series of inductances in parallel with three resistances, in normal operation the resistances dissipate 80W during the recharging of the Pulse Forming Network.

The proposal has been made to blow air through the filter via insulated tubes and measure the air temperature at the output. It is the rise ΔT that is important, so the temperature will have to be taken at the input also. That air will cool the resistances is certain, but a simple estimation shows that for a 10°C rise in air temperature, a mass flow of 7 l/s would be needed.

$$80W = 0.080\ kWHours \approx 0.08 \times 3.6 \times 10^6 = 290{,}000 joules/hour$$

The specific heat capacity of air at 500m altitude is approx 997 joules/kg°C, the air density is 1.16 kg/m^3 and if ΔT *is limited to* 10°C

$$\frac{290{,}000}{997 \times 10} \approx 29kg/Hr\ or\ 25m^3/Hr \approx 7\ l/s\ air\ flow$$

The pressure required to provide this air current depends on the physical flow restrictions of the system, a model of 6 x 12mm tubes of 3m length could have a pressure drop of 8.5mm water. (neglecting expansion of the air, due to heating)

$$pressure\ drop\ (mm\ H_2O) = \frac{flow\ (m^3/s)^2 \times length\ (m) \times density\ (air = 1)}{8.4 \times 10^{-6} \times diameter\ (mm)^5}$$

A fan such as SCEM 06.61.91.930.2 could produce 30l/s at this pressure.(table 1)

Table 1: ETRI fan data, flow in l/s

Static Pres. mm water	**Etri 148**	**Etri 125**	**Etri 98**
18	0	–	–
16	10	–	–
14	18	–	–
12	24	–	–
10	32	0	–
8	40	5	–
6	70	13	0
4	80	22	10
2	90	36	20
0	100	43	26
SCEM 06.61.91.–	**–930.2**	**–948.2**	**–945.5**

This would not give us the important information, the temperature of the resistances, from which we may find the derating factor, only the fact that they are dissipating the 80W as required. The risk of damage would still be present. **These estimations are at equilibrium, when the temperature of the resistances has become high enough** to transfer this energy to the air, as, to raise the temperature of the air by 'n' °C requires the air to be in contact with a body hotter than 'n', the heat transfer depends on the surface area in contact with the air, the radiance of the surface, the gas flow and temperature, etc. So that if the resistance temperature is to be limited, the ΔT of the air should be as low as possible.

MEASUREMENTS

The aim of these measurements is to assign values to the pressure drop of the various parts of the proposed cooling system, to show where improvements or simplifications may be made. By comparing the flow with the static pressure curve of the fan, an effective pressure drop can be inferred.

1.With no power on, air flow at input,

$$\textit{air flow} = \textit{measurement area } m^2 \times \textit{flow speed } (m/s) \times 1000 = l/s$$

Flow measuring cylinder diameter = 14cm = 0.015 m^2

Table 2: Air flow, into filter

Input Fan	plus filter	plus extractor	flow m/s	Volume l/s
yes	no	no	5.3	81
yes	yes	no	5.15	79
yes	yes	yes	5.20	80
yes	blocked	no	5.1	78

These values show the input flow has virtually no dependance on the load. The last test with the filter blocked at the Faraday Cage end, showed an input of 5.1m/s. From this we concluded there was a leak.

It was then decided to measure the flow out of the filter, output flow area, 23mm dia. = $4.5\times10^{-4} m^2$. In the light of the extreme turbulence in the entrance to the input fan, a baffle was placed in the air measuring cylinder which provided more accurate values of input flow.

Table 3: Filter air flow

	min	max m/s	Volume in,l/s	volume out,l/s	dT
cage extraction only	0.0	0.2	1.0	9.5	8 C
1 fan, no extraction	2.38	2.66	38.25	5.4	–
1 fan, with extraction	2.35	2.66	38.24	12.2	6 C
2 fans, no extraction	2.26	2.45	38.10	–	–
2 fans, with extraction	2.15	2.68	38.21	–	6 C

There is little relation between the input air flow and that into the faraday cage, due to the leaks caused by the connections between the resistances and the coils of the filter. The air flow into the filter will cool the first resistance, the suction of air into the faraday cage will cool the third resistance, the amount of flow over the middle resistance is unknown. The temperature rise measured is primarily due to the dissipation of the third resistance $\approx 30W$. Following the preliminary flow results, some modifications were made before continuing with the tests.

IMPROVED FILTER TESTS

A filter has been modified, the holes of the supports in the filter have been enlarged from 4 times 28mm dia to 4 times 50mm dia. and the lateral air leaks have been reduced. The aim is to give a constant airflow over the length of the filter and therefore more consistent cooling of the resistances.

1/ Two fans plus cage extraction

ref.voltage kV	temperature rise
21	+2 C
25	3 C
28	4 C
30	6 C (normal operating point)

2/ One fan plus cage extraction

30	7 C

3/ cage extraction only

30	8 C

From this data it can be seen that there is adequate cooling without the need for extra ventilators.

CONCLUSIONS

The original damage seen was due to high current density at the junction of the metalized resistor contact and the carbon rod, due to skin effect. The improved mounting arrangement should eliminate that risk. We hope that by increasing the air flow over the resistances the reliability will be further improved, that they were hot was indicated by the failures of the 'nylon thread fire detection system'. These threads were tied to the body, not the connections, so their 'burning' was the result of a surface temperature of well over $120°C$. Reducing the body temperature increases the rating of the resistors and their lifetime. It has been shown that with these design modifications the cooling is satisfactory.

One outstanding problem is the accumulation of dust in the filter and faraday cage, ultimately this will cause tracking paths which will require further work. Two possibilities exist, one is to filter the air before it enters the HV filters, this will reduce the 'natural' air flow into the cage, also this requires ducting to connect between the air filter and the HT filter and a fan to overcome the air filter impedance. An other option is to reverse the direction of flow of the faraday cage cooling such that clean air will come from the cage and cool the filter in passing. This will need further study and offers the possibility of improving the cooling of the Thyratron as well, at present the hot air from the Thyratron heats the entire faraday cage.