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COMPARISON OF THREE 108-MHZ SYSTEMS FOR 1.6 MW

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Summary

Advantages, disadvantages and performance of two completely different amplifier cavity types, together with the three high power tetrodes RS2074SK (Siemens), TH518 (Thomson CSF) and 8973 (Eimac) are reported.

Introduction

The rf levels of the Alvarez cavities of the Unilac were initially limited by parasitic UHF oscillations and under-rated parts of the TH518[1]. The power capability of this tube type was not essentially improved until 1979, when the planned Unilac upgrading[2] gave an actual necessity for reaching the full rated power of 1.6 MW per amplifier. The two added cavities and the older cavities could no longer be driven by two parallel amplifiers as before. A parallel drive was not possible because of missing space and lack of fonds for additional amplifiers and power supplies. In this situation GSI started three parallel activities:

1. A replacement of the TH518 by the new Siemens tube RS2074SK was studied at GSI.
2. A contract was given to Herfurth company for developing and building a prototype amplifier[3] with the Eimac tube 8973.
3. Elaborate investigations on the parasitic modes of the TH518 were started at GSI.

All three ways resulted in achieving 1.6 MW, but with different performance.

Amplifier Cavities

Principle drawings of the both tested amplifier types are given in[3] [4]. For further understanding, the main characteristics of the GSI-type amplifier (1) and the Herfurth-type amplifier (2) are listed in table 1.

anode circuit	1	coaxial folded full λ resonator
	2	mixed coaxial and "pancake" 3/4 λ resonator
anode dc blocker	1	not necessary because of folding
	2	64 ceramic capacitors, always 2 in series
output coupling	1	mixed inductive and capacitive, variable
	2	dominant inductive, little variable
g1 - g2 circuit	1	coaxial folded λ/2, anti-resonant
	2	mixed coaxial and "pancake" λ/2, anti-resonant
g1 - g2 blocker	1	coaxial capton capacitor
	2	circular disc teflon capacitor
g1-cathode circuit	1	λ/4 transformer, serial + parallel stub tuners
	2	loaded λ/2 resonator
input coupling	1	direct
	2	mixed inductive and capacitive
cathode blocker	1	coaxial capton capacitor
	2	not necessary
common		cathode driven, g2 connected to earth

Table 1

The Herfurth design shows three main advantages. At first, there are no complicated parts in the whole amplifier; this makes it very simple and cheap to be built. The second one is the easy access to all parts of the anode circuitry, which is most useful during the developing time. The third, relating to parasitic oscillations, is described in detail in a following section.

Before comparing details of the amplifiers actually built, it has to be said, that both types are still at a stage, where further improvements are necessary.

The voltage capability of both cavities is satisfactory in steady state operation. Nevertheless, the following failures did occur with the Herfurth cavity: burnt insulators in the output lines; flashes in the anode circuit which probably resulted from a high level of 3rd harmonic; burnt spring contacts of the screen-grid connector, caused by the nickel plating of the tube; a broken silicon pipe with a lot of soda in the amplifier and some more smaller failures. The GSI cavity still tends to sparking at levels over 1.6 MW at the coupling loop and the shielding of the ferrite absorbers. Both will be improved in 1983.

The GSI type cavity is more favorable for maintainance. A complete disassembly would be possible in about half the time compared to the Herfurth cavity. The same time factor is valid for a tube change, but this is more due to the large number of water connections of the Eimac tube and the necessary absorber cooling of the 8973 than on the cavity itself. For example, a RS2074SK in the GSI cavity may be changed easily in about 40 minutes, including 15 minutes cooling down time of the tube.

In 1983 the Siemens tube RS2074SK will be tested in the Herfurth cavity. The mechanical preparations of the necessary adaptor have been completed and electrical tests will follow soon. Better comparison possibilities of the two cavities will be given, when one tube can work in both cavities. Better comparisons of the RS2074SK and the 8973 can then also be done.

Tube Performance

One of several TH518 reached 1.6 MW with 25 % duty cycle over a three hour test, but got a poisened cathode some weeks later by a microleakage. The reason for the failure of all the tested TH518 at high frequencies is still an overheating of tube internal parts by rf.

Fig. 1: Tubes tested at GSI.

All of five tested Siemens tubes RS2074SK and the one available Eimac 8973 continued to routinely deliver the specified power of 1.6 MW.
The maximum peak power at nominal duty cycle was achieved with a RS2074SK, which delivered 2 MW to a waterload and 1.8 MW to an Alvarez cavity.
The TH518 and the 8973 delivered a little more than 1.6 MW to a waterload, higher levels not being tested.
Some data for reaching 1.6 MW are compared in table 2.

δ=25%	TH 518	RS 2074 SK	8973
U_f/V	18.55	12.5	18.5
I_f/A	423	880	650
P_f/kW	7.85	11	12.025
$-U_{g1}$/V	550	635	540
I_{g1}⎍ /A	~2	~2	~2
U_{g2} /V	1450	1450	1450
I_{g2}⎍ /A	3.2	3.8	4
U_a/kV	22.5	22.5	22.5
I_a⎍ /A	104	112	112
P_-/kW	585	634	634
η/%	68.4	63.1	63.1
P_{Drive}/kW	21	23	23

Table 2

The ceramic insulator between anode and screen-grid and some other outer tube parts of the RS2074SK and of the TH518 reached temperatures in the range of 200° C, while the 8973 reached only about 100° C.
With respect to the losses of a tetrode in rf operation, usually the dissipation of anode, screen- and control-grid by the electron bombardement and the rf losses of the grids are calculated. In addition to the losses in the ceramics, we found, that the rf losses on the cathode must also be taken into account. We measured the rf losses on the cathodes using the following approximate technique: The dc resistance of the filament is a function of its temperature and therefore of its power consumption. The nominal filament data of the three tubes are given in table 3.

	U_f/V	I_f/A	P_f/kW	R_f/mΩ	cylindric space A/cm²	P_f/A W/cm²
TH 518	23	500	11.5	46	~830	13.8
RS 2074 SK	13.5	915	12.35	14.75	~922	14.4
8973	18.5	650	12.025	28.5	~952	12.6

Table 3

As thoriated tungsten is used as cathode material for all the three tubes, the normal operating temperature has to be similar. In rf operation the temperature of the cathode and the resistance rises. Keeping the resistance of the filament constant by reducing the dc filament power P_{fdc}, in a first approximation, one can also assume that the average temperature remains constant. The missing dc power ΔP_{fdc} is then equivalent to the rf losses of the driving current on the cathode:
$\Delta P_{crf} = \Delta P_{fdc}$

Neglecting the current through the top capacitance of the tube and the sinusoidal voltage distribution between cathode and control grid , this current follows the function
$I_{dr}(z) = I_0\ (1 - z/L)$, when $z = 0$ denotes the beginning of the active system, $z = L$ the end, Z_1 its characteristic impedance and $I_0 = \sqrt{P_{Drive}/Z_1}$ with a matched input impedance.
The total rf losses on the cathode are then given by $P_{crf} = \int_0^L I_{dr}{}^2(z)\ R'_c(z)\ dz$, and with the assumption $R'_c(z)$ = cathode resitance per length = const.:

$$P_{crf} = I_0{}^2 \bullet R'_c \bullet L/3.$$

Fig. 2 shows the rf loss distribution over the length of the cathode.

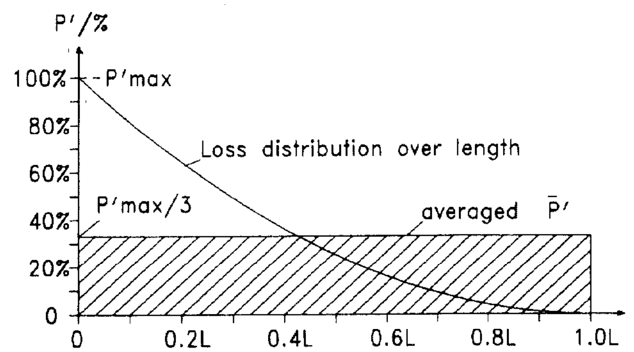

Fig. 2: Cathode rf losses.

Note that the losses per length which occur at the beginning of the active system are three times higher than the averaged losses, which can be measured by ΔP_{fdc}.
How far away the assumption $R'_c(z)$ = const. is from reality can be found by comparison of the nominal dc filament power per length $P_{fdc}/L = P'_{fdc}$ and P'_{max}. For the TH518 ΔP_{fdc} = 4 kW had been measured. This means that P'_{max} is equal P'_{fdc} and R_c will be very strongly dependent on z. Therefore P'_{max} will be more than 3 times the averaged P', making the situation even worth.
For the RS2074SK ΔP_f = 2 kW was found at 400 kW output.
The 8973 could only be measured up to 300 kW. No change in filament resistance was measurable at this level.
One gets a rough idea about internal tube losses by measuring the $\lambda/4$ resonances of the tube's interelectrode circuits with shortened ceramic insulators first through the frequency and associated loss distribution and secondly the Q-value of this resonator. Until now only the measurements of the anode screen grid resonances are completed and given in table 4.

anode screen-grid $\lambda/4$ resonance	f	Q
TH 518	147	92
RS 2074 SK	108	417
8973	147	387

Table 4: $\lambda/4$ resonances of the anode screen-grid resonator.

Parasitic Oscillations

The extensive measurements made on this subject consisted in "cold measurements" with dummy tubes and amplifiers, tests with dc currents up to the limit of anode dissipation, pulsed currents up to 5 MW anode losses and finally rf operation to a waterload and cavity. All the three different tube types showed their ability to produce UHF self oscillations when fitted into an VHF amplifier- surrounding. It was generally found, that an oscillation can start for instance at 20 A anode current and disappear beyond 80 A. Static operation, and in particular pulsed dc operation, proved to be the most critical for exiting parasitic modes. The reason for this is probably the fact that a high Q-value resonator for the parasitic TE modes in the frequency range of about ten times the working frequency cannot be filled during one/half period of the fundamental wave. A low Q-value resonator will not fulfill the amplitude condition of self exitation at all.

The tendency for producing these parasitics can be directly compared with the TH518 and the RS2074SK when placed in the same amplifier.

- TH518: Without proper damping measures (about 20 different absorbers had been tested without significant improvements) the TH518 showed dominant oscillations at 754 MHz and 1200 MHz. A tube internal absorber provides a good damping of the TE110 resonance of the anode screen-grid resonator and makes this tube altogether more "quiet" than the others without additional damping devices in the cavity (fig. 3). The higher frequency oscillations led to internal tube flashes in static operation, and occured also in particular rf operating ranges. Ferrites placed around the anode screen grid ceramic were shielded with copper sheets against the normal TEM modes which nevertheless allowed good coupling for TE modes (fig. 4). In this configuration the TH518 was found to be free of parasitic oscillations when tested with pulsed dc currents up to 200 A and also during rf operation.
- RS2074SK: There are two reasons, why the RS2074SK oscillates more strongly than the TH518. One is the lack of tube internal absorbers, the second is the fact that the supports of the active system are much longer and have big impedance steps, decoupling the tube's interior from the surrounding (fig. 3). The main oscillation frequencies were 720 MHz, 920 MHz, 1310 MHz and 1420 MHz.(600 MHz was once produced without screen grid voltage.) Even together with the above described ferrite absorber parasitic oscillations still occur in dc tests, but no longer during rf operation.
- 8973: The 8973 is operated in the Herfurth cavity, which has the advantage that there is no metallic wall near to the anode screen-grid ceramic of the tube. It could be seen that with damping resistors at the slotted amplifier's discs, parasitic oscillations still occur in rf operation. However, the 8973 permits a very simple damping method. As the supports of g1 and g2 are very short, there is a good coupling of dampig devices in this area to the active system. A ferrite absorber which consisted of a lot of small ferrite rings, cooled by liquid soda inside a silicon pipe between g1 and g2, was enough to make the tube "quiet" in rf operation. It still oscillates in dc operation, while the starting current (2 ... 20 A) depends on anode voltage, positioning of tuners etc. The observed main oscillation frequencies were 832 MHz, 931 MHz and 1300 MHz.

The operation of the RS2074SK in the Herfurth cavity in the near future will allow better comparison of the oscillation tendency of these tubes.

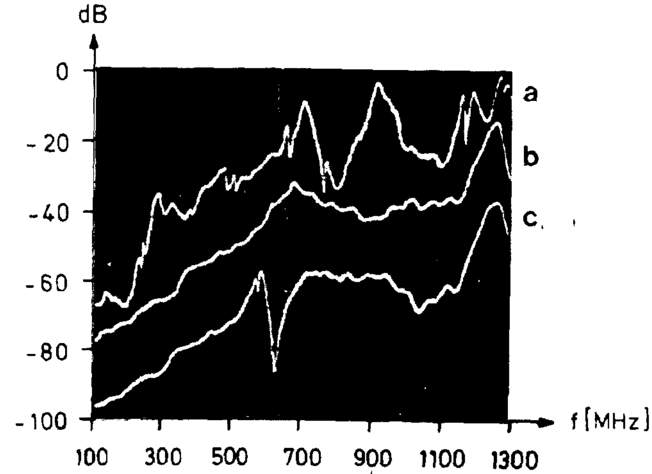

Fig. 3: Transmission through the anode screen-grid resonator with free space around the tubes.
a - RS2074SK, b - TH518 without internal absorber, c - TH518 with internal absorber.

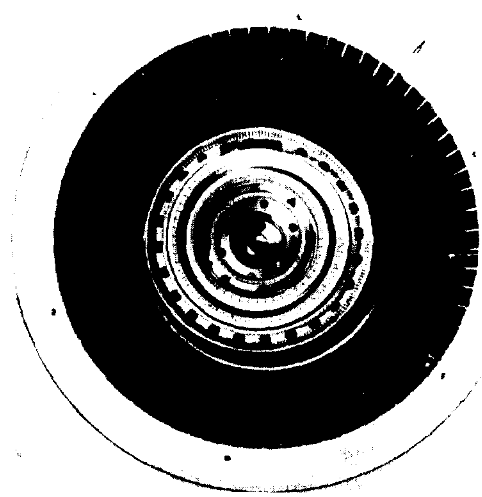

Fig. 4: Shielded ferrite absorber in GSI cavity.

Conclusions

The Siemens RS2074SK together with an improved GSI-type cavity has a proper power capability for routine Unilac operation. The tube is much cheaper than the 8973 and has become the first choice for GSI. The TH518 is only able to feed the divided Alvarez cavities. Work is going on at the manufacturer to raise its power capability at higher frequencies. The 8973 gives probably the biggest reserve in thermal power at the measured frequency. The Herfurth cavity is a cheap alternative to coaxial cavities (with the same power capability) and has some additional advantages.

References

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