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A NEW APPROACH FOR HIGH POWER SOLID-STATE DRIVERS USED TO WIDE-BAND RF ACCELERATION.

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Abstract

The design of an all solid-state amplifier for driving the RF power amplifier of an accelerator has conduced to the realization of a 400 W wide band driver, including four double push-pull 100 W modules, input-and output-coupled on 50 Ω load and source impedances, with matching of the power amplifier by low-pass or band-pass two-π filter.

1. Introduction

The designed solid-state driver is an equipment utilizable for all wide-band applications relating to the RF particle acceleration; and the principal performances are as follows :

Useful frequency band	: 800 KHZ to 8 MHZ
Nominal gain	: > 40 dB
Input and output impedances	: 50 Ω
Output power	: 400 W (CW)
Input power	: < 40 mW
Harmonic distortion	: <- 20 dB for all harmonics to 400 W output power.
Collector efficiency	: > 37 %

The driver is realized by association of four 100 W modules, input-and output-coupled, to obtain the 400 W required power. The cooling of the heat sinks is air-forced.

The set is designed to form a compact equipment (10 U standard rack) and easy to repair owing to the arrangement of the elements.

The utilization on a 50Ω - load impedance allows to place the driver to a large distance from the power amplifier (i.e. in the equipment room) and to ensure the connection with the power amplifier by a 50Ω-coaxial cacle ; the match of the input-capacity of the power tube is realized by a low-pass two-π filter 50 Ω characteristic impedance.

2. Principle of realization.

(Figures 1 and 2)

Each of the four basic modules includes two stages :

a) An input stage E_i, which can provide 4 W RF-power, constituted by a one-way push-pull amplifier including two TRW PT 5740 class.A biased transistors.

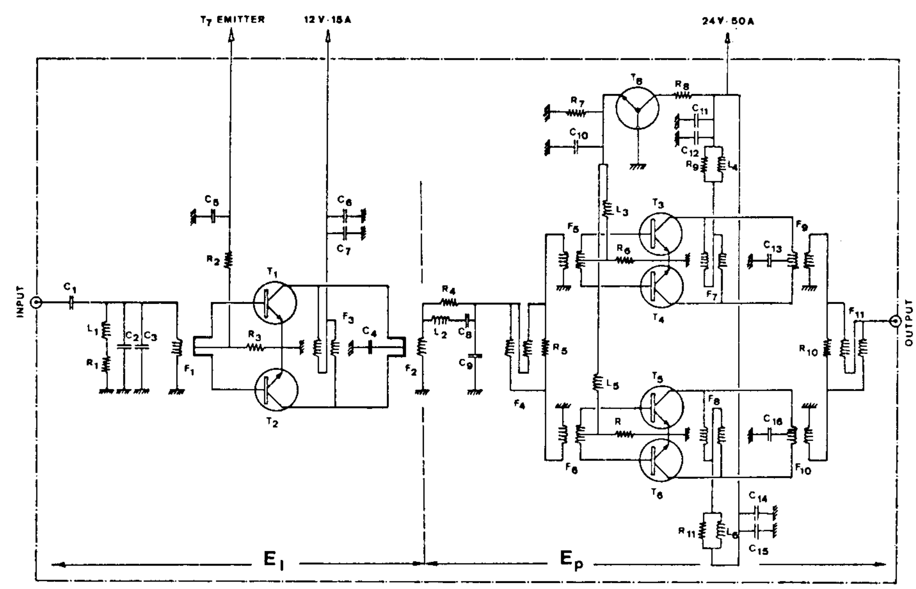

Fig.1 : 100 W. solid-state wide-band amplifier module.

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b) a power stage E_p, constituted by two push-pull amplifiers including four TRW PT 6665 A class AB biased transistors.

As an input for the equipment, a splitter (fig.2) divides the RF input signal (delivered by a 50 Ω-source) between the four 100 W-modules with same amplitude and phase. An output-coupler ensures the summation of four RF amplified signals, to provide the required output level.

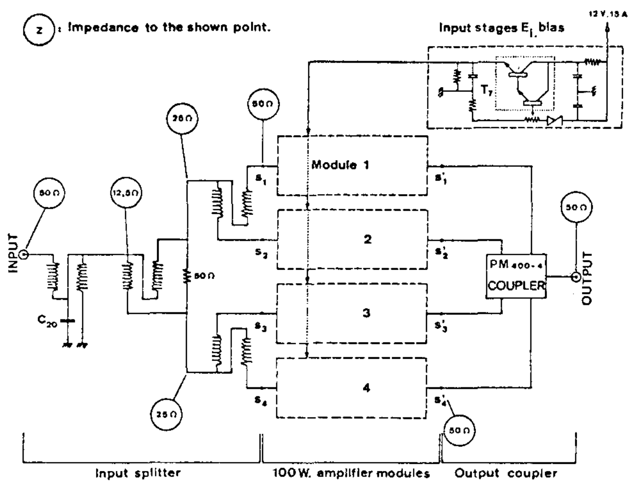

Fig. 2 : 400 w. solid-state modular amplifier and coupling circuits.

The D.C. bias of the set is realized by two external power supplies :

a) a 12 V-15 A supply for the bias of the four input stages E_i.

b) a 24 V-50 A supply for the bias of the four power stages E_p.

3. Power stage E_p

3.1 Principle :

The two branches of this stage are coupled by 0-degree hybrid transformers F_4 and F_{11}, to convert the normal 50 Ω source and load impedance to two 100 Ω parts which are in phase. Any imbalance in amplitude or phase causes power to be diverted to resistors R_5 and R_{10}.

The four transistors are TRW PT 6665 A, which can provide 70 W (CW) to 28 MHz. The ground bias is obtained by a byistor fixed on the heat sink of the transistors, ensuring thus automatically the thermal compensation and D.C. stability.

The collector feed is realized by transformers F_7 and F_8, which combine with the output-matching transformers F_9 and F_{10} to form a 180-degree hybrid combiner[1]. The imput of transistors is matched by transformers F_5 and F_6.

3.2 Realization of transformers :

3.2.1. Input impedance matching transformers F_5 and F_6.

The turns ratio is determined by : $\frac{N_1}{N_2} = \sqrt{\frac{Z_1}{2Z_N}}$

where : $Z_1 = 100\ \Omega$ and $Z_N = \sqrt{|Z_{BF}| \cdot |Z_{HF}|}$

The quantities Z_{BF} and Z_{HF} are the complex input impedances of the transistors at the low-frequency and high-frequency limits ; the values are given by a Smith chart proper for each transistor to a fixed power (here 100 W PEP) :

$$\left.\begin{array}{l} |Z_{BF}| = 7.05\ \Omega \\ |Z_{HF}| = 1.48\ \Omega \end{array}\right\} \quad \frac{N_1}{N_2} \simeq 4$$

Practically, this turns ratio is too high and we chose after experiment a 3:1 ratio.

3.2.2 Output impedance matching transformers F_9 and F_{10}.

The turns ratio is fixed by :

$$\frac{N'_2}{N'_1} = \sqrt{\frac{Z'_L . P_o}{2(V_{cc} - V_{sat})^2}}$$

$$\text{where : } \left.\begin{array}{rl} Z'_L & = 100\ \Omega \\ P_o & = 60\ \text{W} \\ V_{cc} & = 24\ \text{V} \\ \text{and } V_{sat} & = 2.5\ \text{V} \end{array}\right\} \quad \frac{N'_2}{N'_1} \simeq 2.5$$

Transformers F_9 and F_{10} are identical to transformers F_5 and F_6 , with inverted windings.

3.2.3 Hybrid couplers F_4, F_7, F_8 and F_{11}.

This couplers are constituted of 16 turns of twisted pair on a ferrite torus.

4. Input stage E_i.

To increase the gain and allow to drive directly this amplifier by a low-level RF generator,each of four power-stages E_p is preceded by aninput-stage E_i, including a hybrid coupler F_3 and two impedance matching transformers F_1 and F_2. This transformers offer the particularity of having a winding composed by a single turn constituted by two hollow parallel copper tubes (fig.3) ; the ferrite torus are filed· on this tubes and the other winding is threaded in continuous turns through the brass tubing (4:1 ratio for F_1 and 1:3 for F_2).

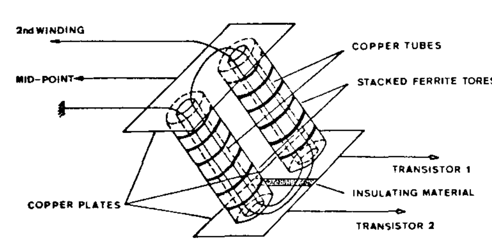

Fig. 3 : Impedance matching transformer with single turn .

The match between E_i and E_p is ensured by a corrector network placed between F_2 and F_4.

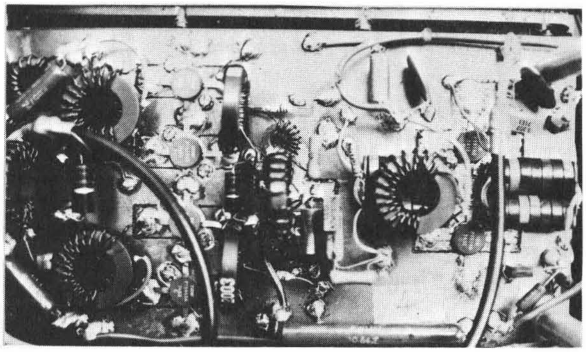

Fig. 4 : 100 W. amplifier module (plan view).

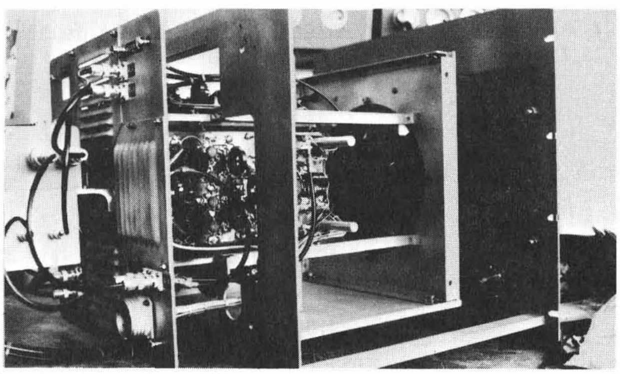

Fig. 5 : 400 W. Driver with two removed panels (side view).

5. Driver performances.

5.1 Gain (fig.6)

The gain, maximum to lower frequencies, can be equalized by an AGC, with a weak dynamic range.

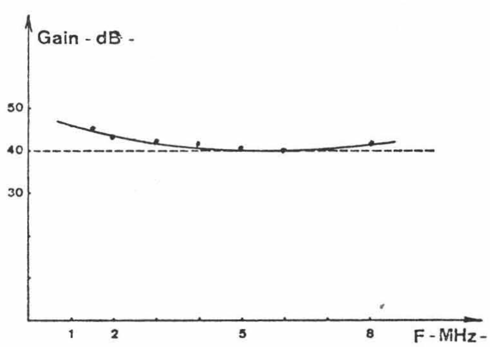

Fig. 6 : Gain versus fréquency .

5.2 Collector current (fig.7)

This current decreases with increasing frequency, consequently the collector efficiency increases from 37 % to 67 % for 400 W output power.

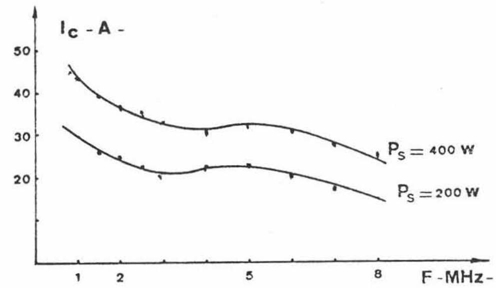

Fig. 7 : Collector current versus fréquency.

5.3 Input impedance of each 100 W module (fig.8)

The maximal mismatch is observed to the highest frequency, where : $|Z| = 62\,\Omega$

We can thus deduce for use of this driver :

SWR $\leqslant$ 1.24

Reflexion factor : K $\leqslant$ 0.107

$$\frac{\text{Reflected energy}}{\text{Incident energy}} \leqslant 1.15\ \%$$

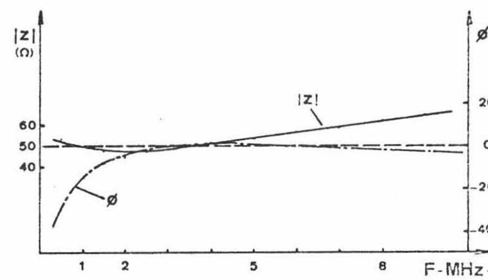

Fig.8 : 100 w. modules input impédance.

5.4 Harmonic spectra

As all push-pull amplifiers, this driver reduces strongly the even-order harmonics and moderately the odd-order harmonics. Also the third harmonic is rather high, especially for lower frequencies, where the low-pass output filter is ineffective. The 2nd harmonic is ever below -40 dB, the 3rd below -20 dB, the 4th below -35 dB, the 5th below -30 dB and other -38 dB.

6. RF Power amplifier matching filter.

(fig.9)

The power amplifier uses a tetrode TH 120, with an input capacity of about 540 pF ; this capacity is the central element of a low-pass filter constituted by two π-cells in series, with $50\,\Omega$ characteristic impedance and cut-off frequency upper to the highest frequency to use driver.

The parameters R_c, F_c, L and Ce are connected by the relations :

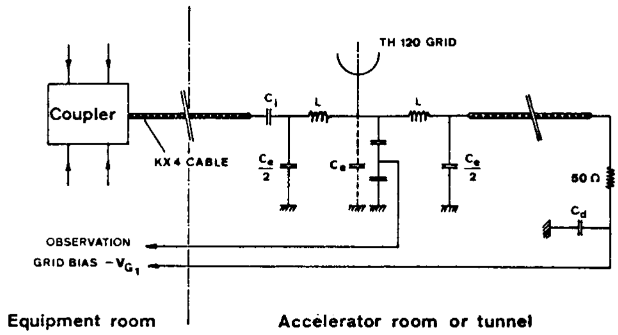

Fig. 9: HF power amplifier matching filter.

$$F_c = \frac{1}{\pi\sqrt{LCe}} \quad \text{and} \quad R_c = \sqrt{\frac{L}{Ce}}$$

where : $R_c = 50\,\Omega$ and $Ce = 540$ pF

We obtain : $L = 1.35\ \mu H$ and $F_c = 11.8$ MHZ

References

1) Pitzalis Jr. O. and Couse T. - Broadband transformer design for R.F. transistor power amplifiers.

Proceedings of the electronic components Conference 1968 - New-York . p.207 - 216.