The vacuum tube distributed amplifier

I want to spend few words about a smart solution found in the past to the apparently insoluble problem of building very wide band amplifiers.

When the frequency raises, the bandwidth of any conventional amplifiers is limited by its gain decrease, until the gain of each stage approaches the unity. William Percival in 1936 proposed the architecture of the distributed amplifier to overcome this limit: two or more tubes are connected in such a way to have their anode currents, and hence their outputs, summed in the load impedance, although the parasitic capacitors are not paralleled. Figure 1 illustrates this principle.

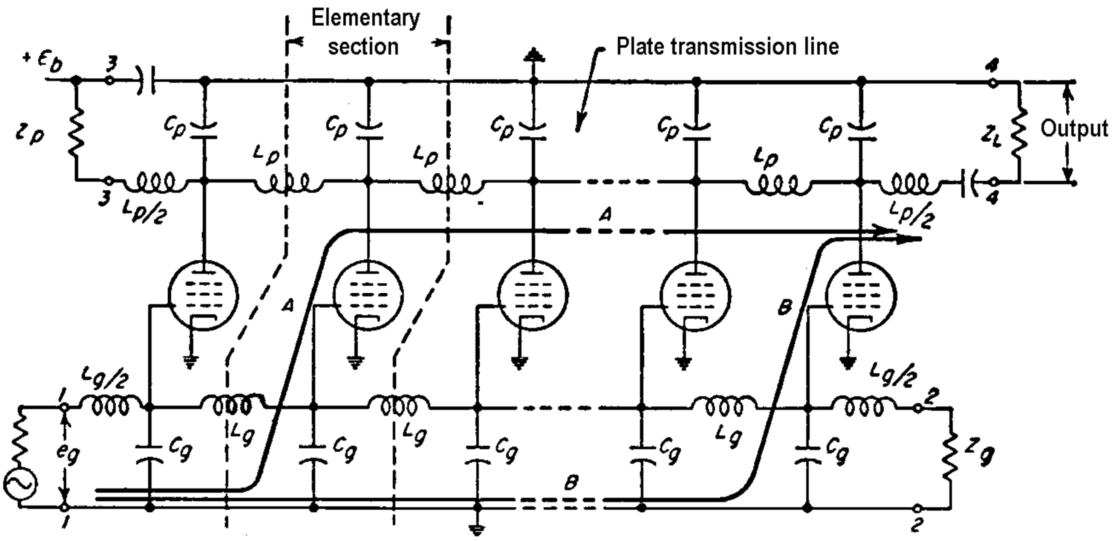

Fig. 1 - Simplified diagram of a distributed amplifier

Grids and plates of the vacuum tubes are connected to the intermediate taps of two transmission lines, formed by the inductances Lg and Lp and by the parasitic capacitance of the tubes themselves, Cg and Cp. The two lines give the same phase delay on the grid and on the anode of each tube. Consequently the output of each tube appears in the plate line exactly in phase with the output of other tubes, summing all together, after a time equal to the propagation delay of the plate line, in the output load impedance Z_l. If the output impedance matches the plate line impedance Z_p, then the output voltage will be $1/2(e_g*g_m*Z_l)*n$, where n is the number of the tubes. The voltage gain of the amplifier with n tubes is therefore $1/2(g_m*Z_l)*n$. Making n great enough, or using the right quantity of tubes, the gain of the amplifier can be made as high as needed, even when the gain of each tube, g_m, is lower than unity. The bandwidth of this amplifier is therefore limited essentially by the cut-off frequency of the transmission lines.

Amplifiers built according to this principle were used since the early fifties in some critical applications. In the vertical deflection stages of high-speed tube oscilloscopes, since the mid fifties, the distributed amplifiers found their most profitable use. Tektronix, among the others, used this circuit inside its wide band mainframes, offering top performances and bandwidth, well exceeding those of its competitors.

In the next figure it is given the partial diagram of the distributed vertical differential amplifier of the Lavoie LA-265A oscilloscope, similar to Tek 545, a design of the mid fifties. A bandwidth exceeding 30 MHz, starting from DC, and a risetime better than 12 ns were possible with this differential amplifier. Differential input voltage is applied to Ia and Ib. The outputs A and B drive the vertical deflection plates through the vertical delay line. Just to give a term of comparison, a 535 mainframe, with conventional amplifier stages, had a bandwidth limited to 15MHz.

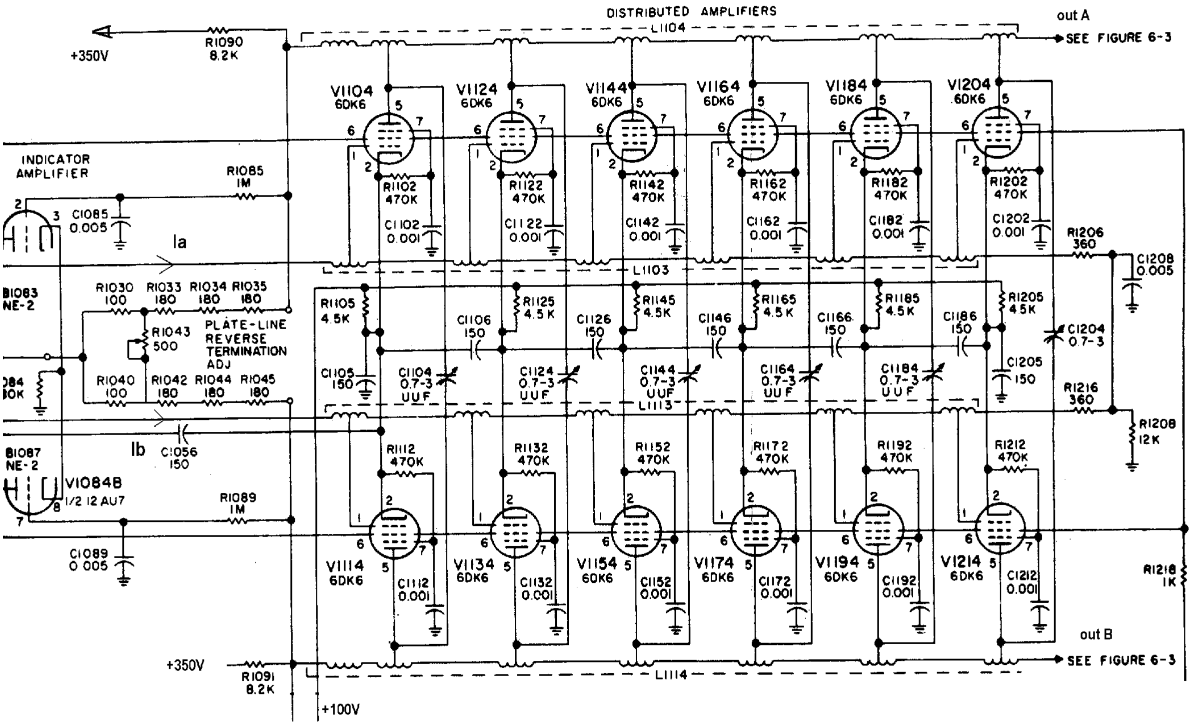

Fig. 2: Each section of the four transmission lines, the tapped inductors of L1103, L1104, L1113 and L1114 between each stage and the associated parasitic capacitance, provides approximately 3 ns delay. A total delay of approximately 15 ns is then introduced by the distributed amplifier. This delay adds to the 185 ns of the vertical deflection delay line, to give 200 ns total delay.

The next figure gives a simplified diagram of the first distributed amplifier of the Tek 585A, about early sixties.

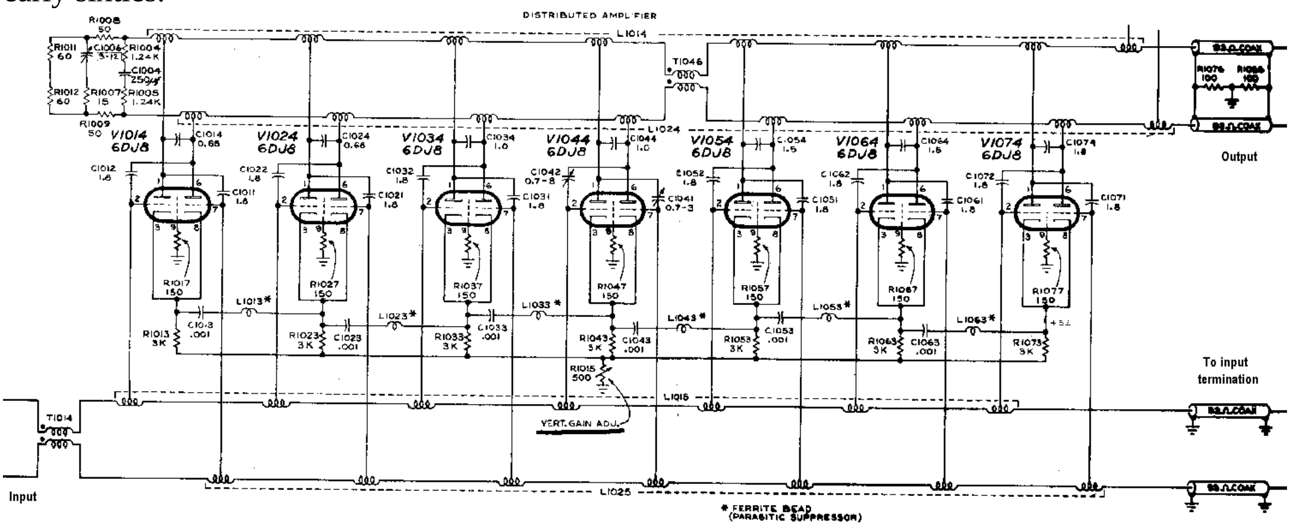

Fig. 3: First of the two distributed amplifiers used in the vertical deflection of the Tektronix 585A mainframe. This section is between the input plug-in and the vertical fixed delay line.

Figure 3 gives the partial diagram of the first one of the two distributed amplifiers used by Tektronix in its 585A mainframe. The amplifier was between the vertical plug-in connector and the fixed delay line, while a second one amplified the signal from the delay line to the CRT vertical deflection system. The pulse transformer on the input lines, T1014, and the one, T1046, on the plate lines prevent common mode oscillations.

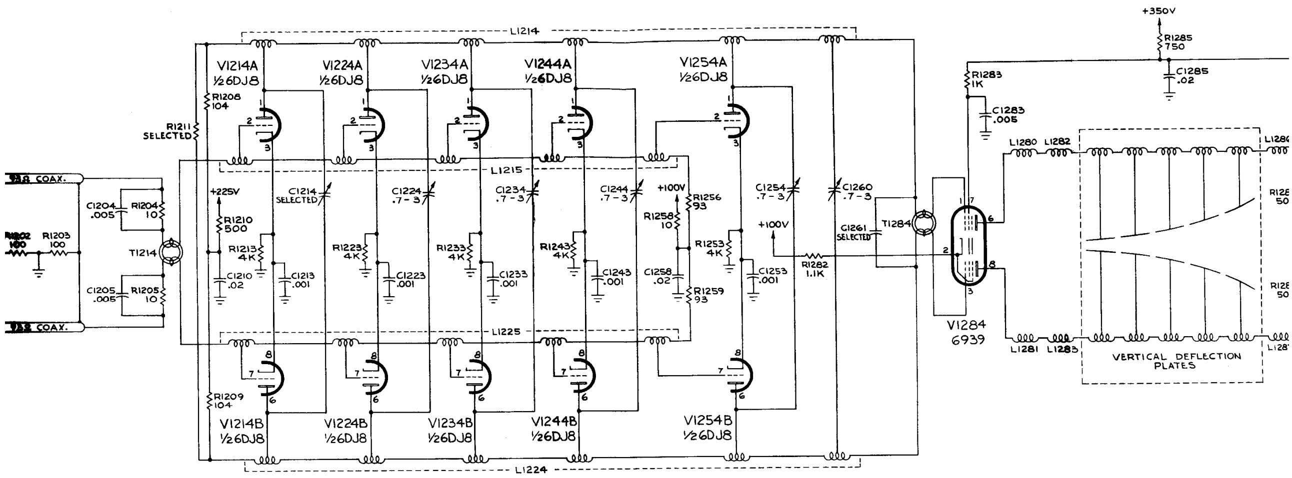

Fig. 4: Vertical amplifier, CRT driver stage of the Tek 585 mainframe, year 1959.

Figure 4 shows the diagram of the CRT driver stage: the second distributed amplifier is between the fixed delay line and the CRT. This stage is similar to the first amplifier, the one which drives the delay line, but uses five double triodes. All triodes are neutralized to prevent oscillations. The distributed amplifier drives a push-pull power stage, V1284, and then the vertical distributed deflection system of the CRT.

In its 585 mainframe Tektronix used 13 tubes just for two gain stages of the vertical amplifiers: a lot of tubes indeed! However the result was an hard to believe vertical bandwidth from DC to about 100 MHz and the overall risetime was better than 3.9 ns. An extraordinary result for an oscilloscope first introduced in 1959, when the average competition was well under 5 MHz!

The performances attainable with this architecture were further enhanced by the miniaturization coming from solid state and microelectronic devices. Still today wide band amplifiers benefit from a circuit first devised in 1936.

References:

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2) Military, T.O. 33A1-13-229-1, Technical Manual Oscilloscope LA-265A
3) Tektronix, type 585 Instruction Manual, 1959
4) Tektronix, type 585A Instruction Manual, 1963