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Improvement of the Bandwidth of the Transient Digitizers in the LIDAR Thomson Scattering Diagnostic on JET

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Abstract. The main limitation on the spatial resolution of the LIDAR Thomson scattering diagnostic on the JET tokamak is due to the narrow bandwidth of the detection system. The transient digitizers, Tektronix 7912AD, are the main contributors to the narrow bandwidth. It is shown how the digitizers can be modified to improve the response time from approx. 480 to 410 ps.

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INTRODUCTION

The LIDAR Thomson scattering diagnostic on the JET tokamak, described in Ref. 1, uses a short laser pulse that traverses the plasma to obtain electron density and temperature profiles.

The spectrum of the back-scattered light is recorded as a function of time by a detection system consisting of microchannel plate photomultiplier tubes and Tektronix 7912AD transient digitizers with 7A29 preamps, upgraded by Tektronix to 800 MHz bandwidth.

As shown in ref. 1, the spatial resolution δL of the system is given by $\delta L=c(\tau_L + \tau_D)/2$, where c is the speed of light, τ_L the laser pulse duration, and τ_D the response time of the detection system. The duration of the laser pulse is 300 ps, the response time of the photomultiplier tubes is 230 ps, and that of the digitizers is 480 ps. From these values, it is clear that the main limitation on resolution comes from the digitizers.

I. CHARACTERIZATION OF THE TRANSIENT DIGITIZERS

In order to investigate the possibilities for increasing the bandwidth of the already upgraded digitizers, one of these units was characterized in detail. A block diagram of the vertical channel is shown in fig. 1. The preamplifier, 7A29, has a 50Ω single-ended input, whereas the internal couplings between the units are differential, 2 x 50Ω, and terminated at both the output of one unit and the input of the next. This allows measurements to be made using standard instruments with 50Ω terminations. (For a description of the vertical channel, see ref. 2.) To characterize the digitizer, the response time and frequency response have been measured for the complete vertical channel. The freqency response has also been measured for the preamplifier, multiplexer, and delay line.

A. Measuring methods

For application in the LIDAR diagnostic, the primary characteristic of the digitizers is their time response. This is measured by using a test pulse with a very short rise time (<40 ps). The pulse generator is a Tektronix 7704A with plug-ins 7S12, S-6 and S-52, where S-52 is the pulse generator and S-6 a sampling unit used for checking the rise time of the test pulse. The pulse in fed to the digitizer, and the step response is drawn directly on the scan converter tube, from where it is read and transferred to an IBM PC for calculating the response time and plotting the result on a matrix printer.

The measuring set-up for frequency response measurements is shown in fig. 2. By means of a sweep generator, the frequency response is drawn directly on the scan converter tube of the digitizer. In order to calibrate the frequency axis, a coaxial stud with known resonance frequencies is inserted between the sweep generater and digitizer. The stud creates a number of narrow notches of known frequency. The data are then transferred to the PC, which processes them and makes the frequency calibration and a proper normalization of the ordinate values. In processing the data, the measurement is also compensated for the frequency response of the generator, based on a measurement by means of a power meter. The results are plotted by the PC.

Frequency response measurements on single units are made by means of the tracking generator and the spectrum analyzer. The data are transferred to the PC to compensate for the frequency response of the tracking generator and spectrum analyzer, followed by normalization and plotting.

B. Measuring results

The step response of the complete digitizer is shown in fig. 3. As can be seen, the rise time (10 to 90%) is 480 ps, which is in accordance with the manufacturer's specification. The overshoot is 9%. This rather high value is probably due to the modification of the bandwidth from 500 to 800 MHz by Tektronix. In the application at JET, the spatial profiles of plasma temperature and density are measured. In order to get a correct measurement of steep changes in the profiles, the project group at JET specified a tolerable overshoot of up to 10%.

The normalized frequency response measurements are given in fig. 4, A through D. A shows the gain of the complete digitizer and the 800 MHz bandwidth as specified by Tektronix. For the 7A29 preamplifier, B shows that the bandwidth varies from approx. 0.9 to 1.4 GHz dependent on the setting of the variable gain control. Thus, it is very important in high-speed applications to use the preamplifier in the calibrated or maximum gain setting. The bandwidth of the multiplexer (fig. 4 C) is beyond 1.5 GHz. It follows that the multiplexer has only a minor effect on the bandwidth of the complete digitizer. In contrast to this, the delay line seriously reduces the bandwidth. As can be seen from fig. 4 D, the bandwidth of the delay line is only approx. 500 MHz. This is partly compensated for by the delay line compensation circuit, but in this case a gain of approx. 6dB at 1 GHz is lost.

C. POSSIBILITIES FOR IMPROVEMENTS

The obvious possibility for increasing the bandwidth is to improve the frequency response of the delay line. By combining fig. 4 A (frequency response of complete digitizer) with fig. 4 D (frequency response of delay line) it can be seen that the bandwidth could be improved to approx. 1.1 GHz, provided the delay line had a flat frequency response. In practice, improvements could be made by (1) using delay line cable with a less loos, and (2) shortening or removing the delay line. As the delay line is a pair of coaxial cables with a length of approx. 12 m, replacement with a low-loss type would be difficult within the available space in the digitizer. Option (2) could be used if the time base were triggered by an extenal signal, which is advanced relative to the signal to be measured. This is indeed the case in the LIDAR Thomson scattering diagnostic on JET.

II. IMPROVEMENT OF THE TRANSIENT DIGITIZERS

Based on the above-measured results, it was decided to modify the 7 digitizers of the LIDAR diagnostic by removing the delay line and designing a new compensation network for the shortest possible rise time and an overshoot of less than 10%.

A. Design procedure

The following procedure was followed for the 7 digitizers:

1. Characterization of the unmodified digitizer by measurement of the frequency response, rise time, and overshoot.
2. Removal of the delay line and compensation circuit. Instead of the latter, an attenuator circuit with flat frequency response and an attenuation equal to that of the original circuit at low frequencies is inserted. The attenuator consists of 2 resistive T-circuits with an insertion loos of approx. 4.5 dB, and matched to the 50 Ω transmission lines. Later in the procedure the attenuator circuit forms the resistive part of a new compensation network.

3. Characterization of the digitizer without the delay line by measuring the frequency response and rise time.

4. The frequency response for an optimum compensation circuit is calculated from the step response measurement and by assuming an ideal step response with a linear transition between the two states and a rise time of 400 ps, and no overshoot. From the actual step response $s_A(t)$, the impulse response $h_A(t)$ is calculated by numerical differentiation. The actual frequency response is calculated as the Fourier transform of the impulse response, i.e.

$$H_A(j\omega) = \mathcal{F}\left\{h_A(t)\right\}$$

In the same way the ideal frequency response is calculated from the ideal step response as

$$H_I(j\omega) = \mathcal{F}\left\{\frac{d}{dt} s_I(t)\right\}$$

The ideal frequency response of the compensation circuit is then obtained as:

$$F_I(j\omega) = \frac{H_I(j\omega)}{H_A(j\omega)}$$

5. The above calculation is used as a guide for designing a new compensation circuit using an interactive procedure. A circuit analysis program, ESACAP[3], is used for calculating the frequency response of the circuit.

6. The step response of the digitizer with the new compensation circuit is simulated using the actual frequency response $H_A(j\omega)$ and the calculated response $F_C(j\omega)$ for the compensation circuit. The frequency response of the digitizer with compensation circuit is $H_C(j\omega)=H_A(j\omega)\cdot F_C(j\omega)$. The impulse response is obtained as

$$h_C(t)=\mathcal{F}^{-1}\left\{H_C(j\omega)\right\}$$

The step response is obtained by integrating $h_C(t)$. If the result does not lie within range of the design then steps 5 and 6 must be repeated.

7. Finally, the circuit is built into the digitizer, and after a final adjustment, the frequency response, rise time, and overshoot are measured.

B. Results

Frequency response measurements for one of the digitizers are shown in fig. 5. Curve A shows the gain of the unmodified digitizer, curve B the gain without delay line and compensation circuit, and curve C the gain with the new compensation circuit. It is seen that the 3 dB bandwidth has been now increased from 0.8 to 1.1 GHz. The step response of the modified digitizer is shown in fig. 6. With reference to fig. 3, it is seen that the rise time has been improved from 480 to 410 ps without increasing the overshoot. The new compensation circuit is shown in fig 7.

(For the connections in the digitizer, see the Tektronix manual[2].)

The results for all 7 digitizers are shown in Table I. It is seen that the average rise time has been shortened from 480 to 410 ps with the overshoot has been kept within 10% as desired by the project group at JET.

ACKNOWLEDGEMENTS

The author would like to express his thanks to Jørgen Bundgaard for many valuable technical discussions and for programming the data acquisition and to John Olsen for carrying out the delicate work of modifying the delay line compensation circuit.

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[2] Tektronix: Instruction Manual 7912AD MOD HB1A.

[3] Poul Stangerup, The Simulation Program - ESACAP. Elektronik-Centralen, Hørsholm, Denmark. ISBN 87-7398-086-2.

TABLE I. Results of the improvement.

Digitizer	Rise time (ps)		Overshoot (%)	
#	Initial	Modified	Initial	Modified
1	480	410	9	10
2	510	402	4	9
3	493	400	9	9
4	452	390	8	9
5	477	400	6	9
6	481	423	8	8
7	443	412	10	8

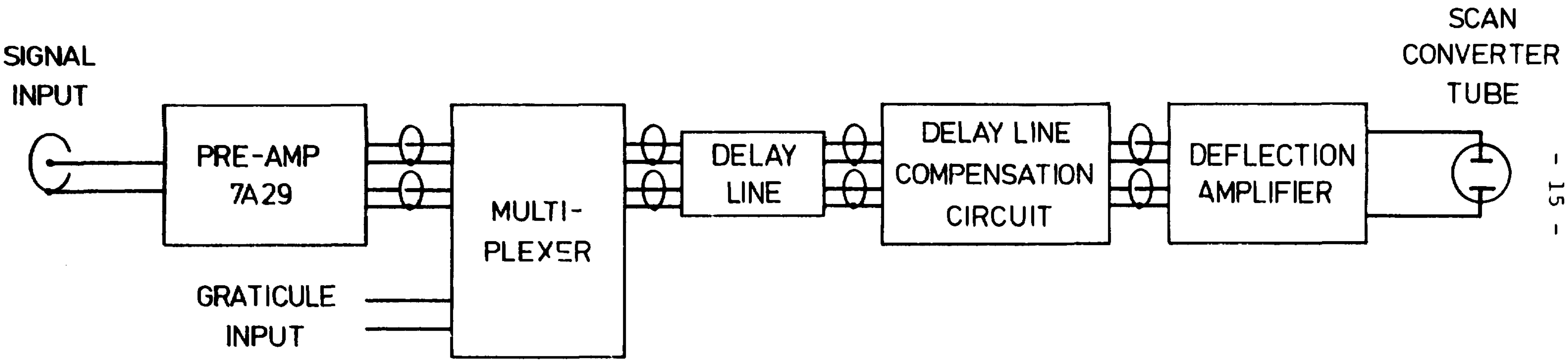

FIG. 1. Vertical channel of Tektronix digitizer 7912AD.

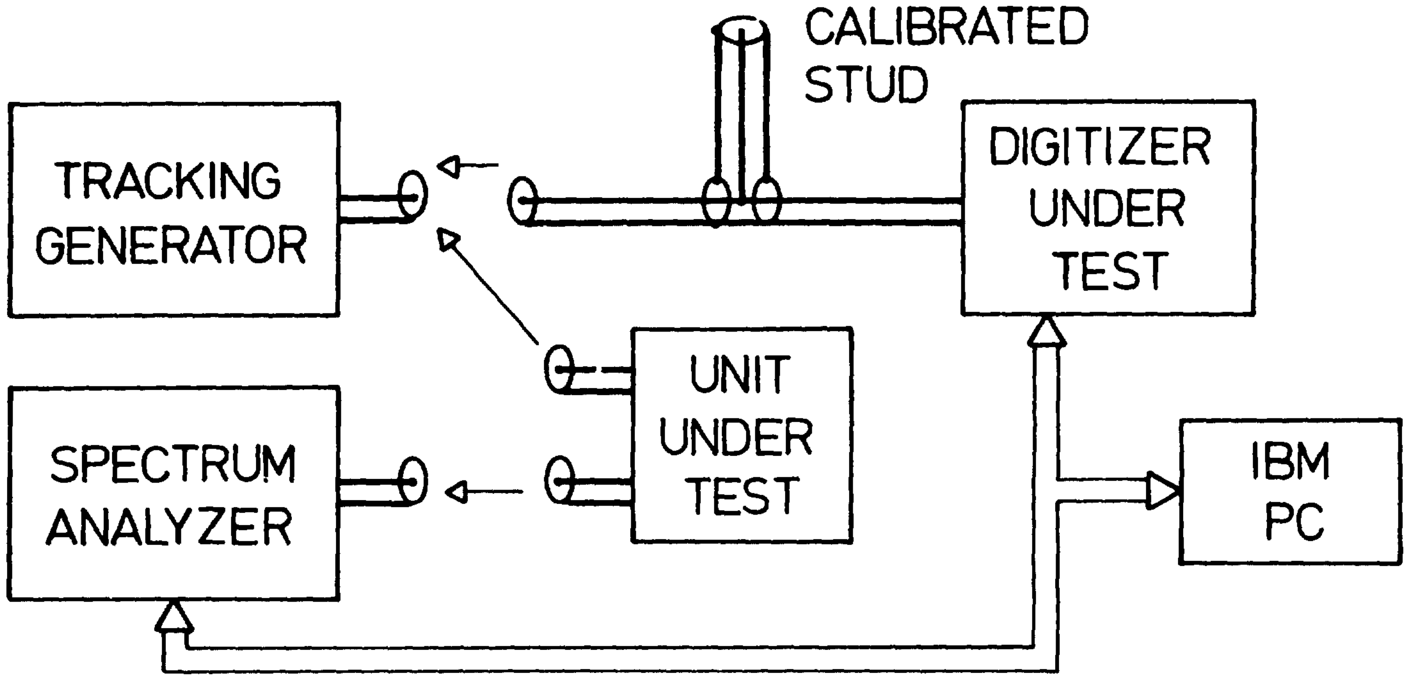

FIG. 2. Frequency response measurements. The spectrum analyzer is a Hewlett-Packard 8567A with tracking generator 8444A-OPT059. The IBM PC is connected to the spectrum analyzer and the digitizer by the GPIB.

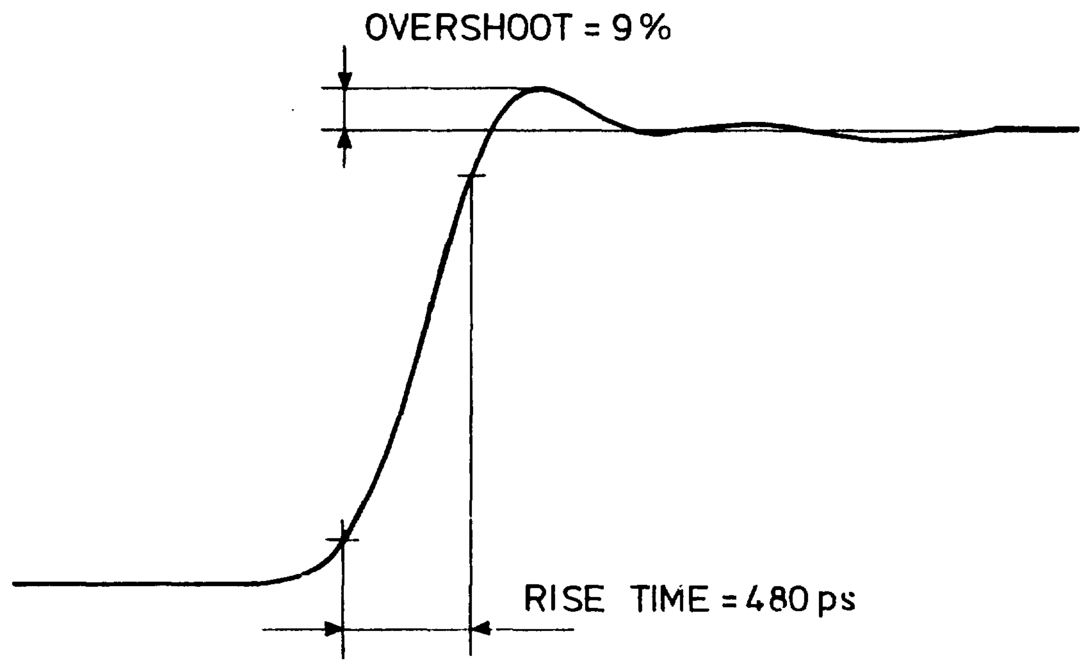

FIG. 3. Step response of complete digitizer. The rise time is measured between the 10 and 90% points of the curve. The 0 and 100% points are defined as the initial and final values, respectively.

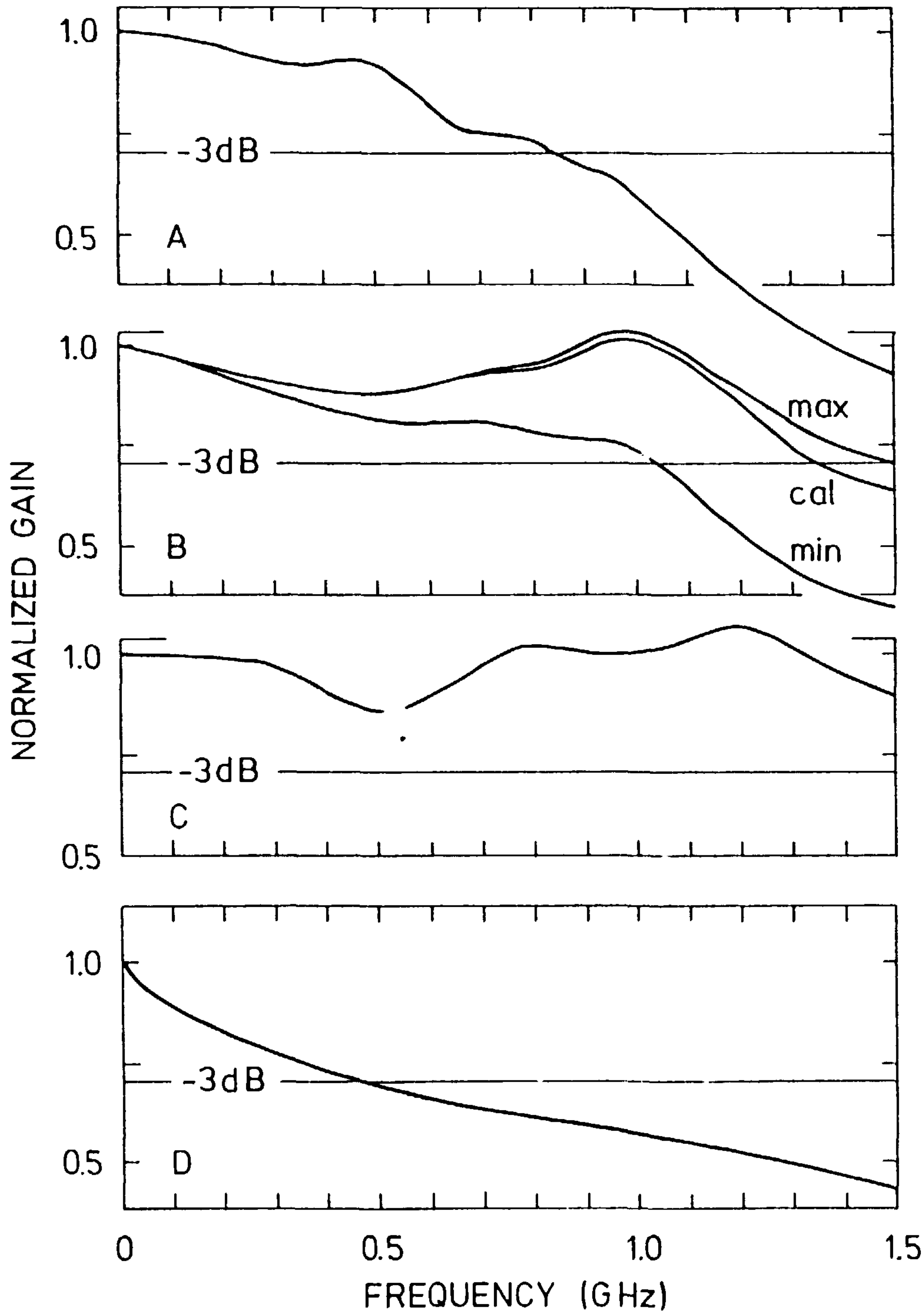

FIG. 4. Normalized frequency response measurements. A shows the gain of the complete digitizer with the variable gain setting of the preamplifier set to the calibrated position. Curves B are the gain of the 7A29 preamplifier with different settings of the variable gain control (maximum, calibrated and minimum gain). C shows the gain of the multiplexer, and D of the delay line.

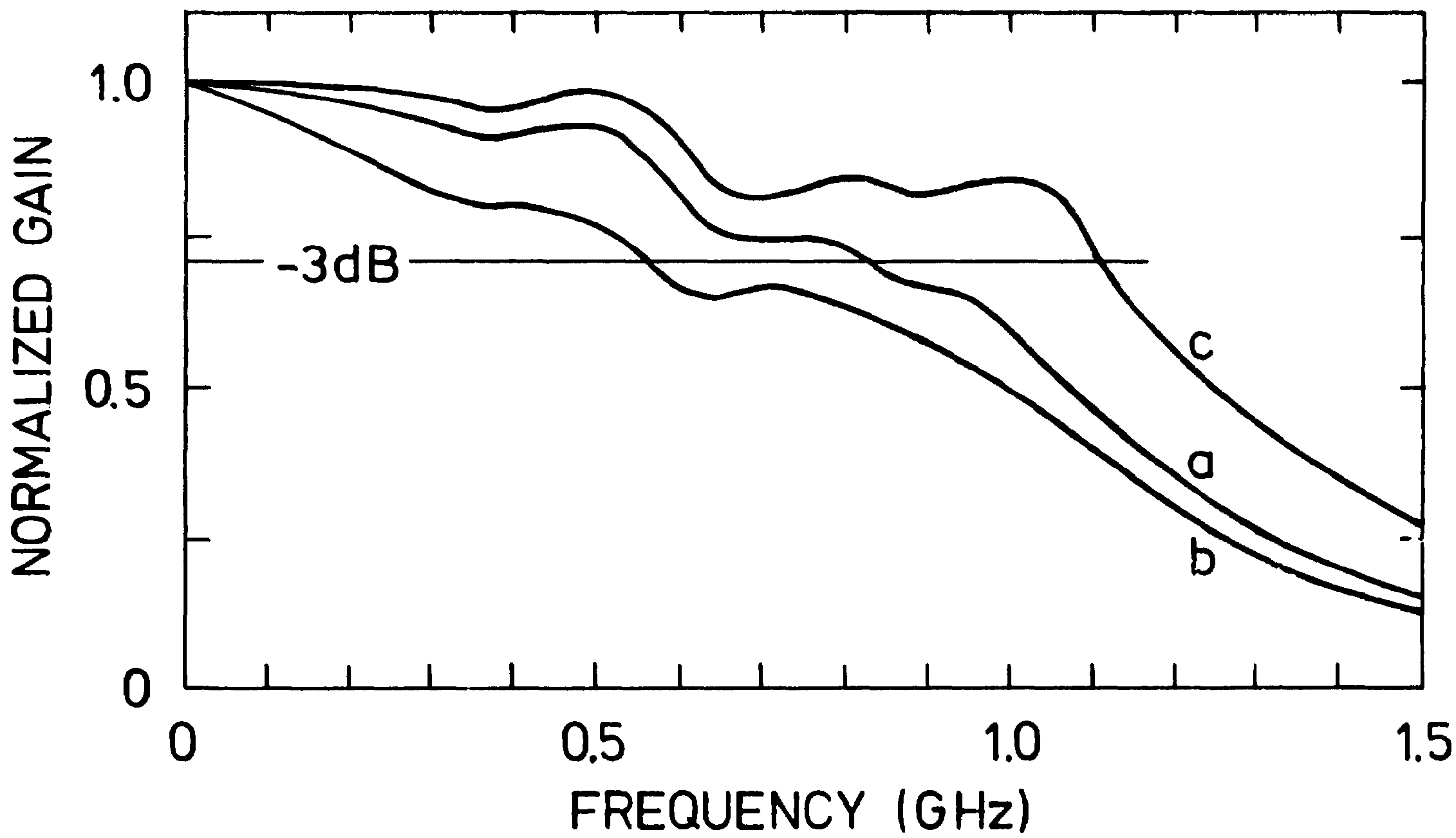

FIG. 5. Frequency response of digitizer. (a) The unmodified digitizer, (b) without delay line and compensation circuit, and (c) the modified digitizer with new compensation circuit.

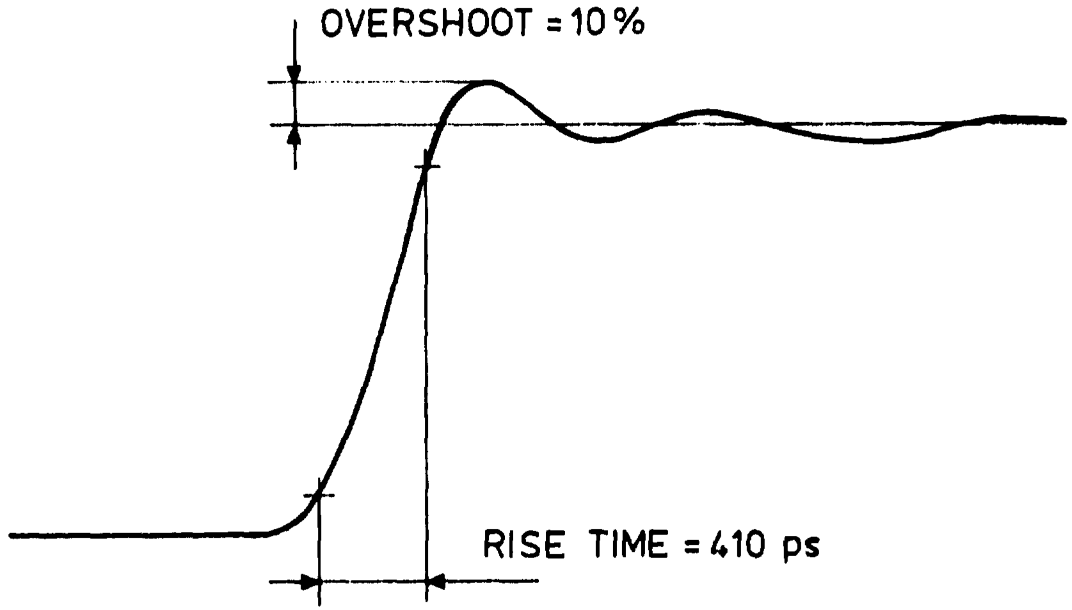

FIG. 6. Step response of improved digitizer.

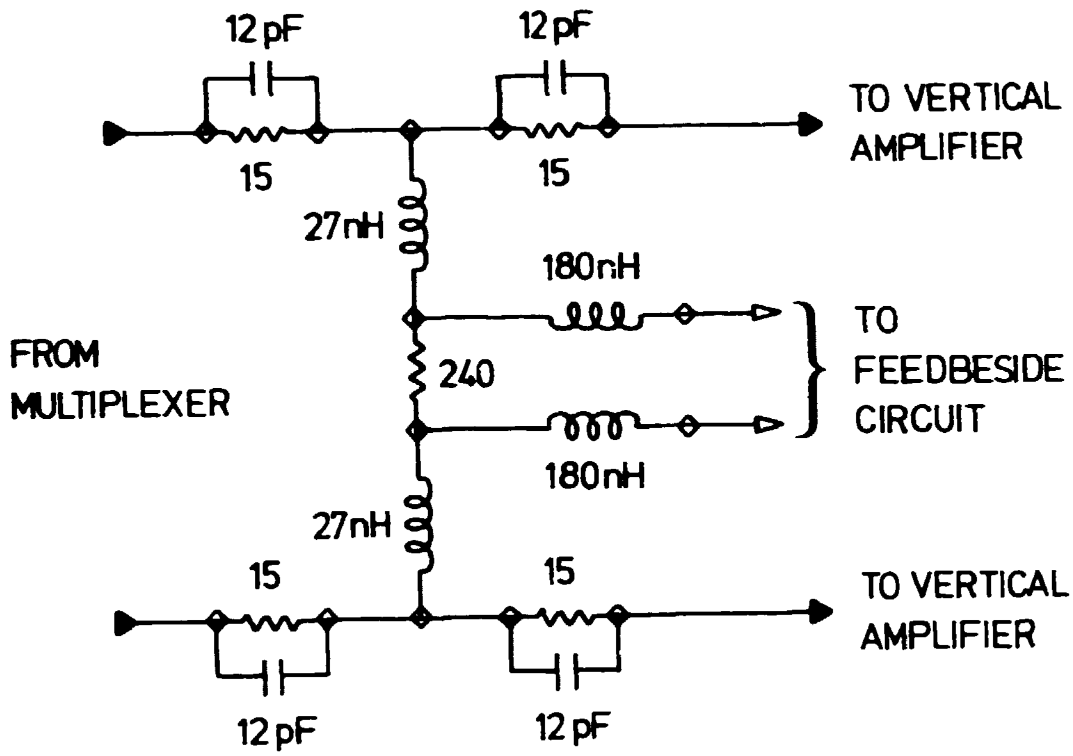

FIG. 7. New compensation circuit. The resistors are mounted as an attenuator circuit during step 2 of the design procedure. The feedbeside circuit in the digitizer is fcr compensating for thermal effects in the deflection amplifier due to the current variation in the transistors caused by the signal. (For details se the Tektronix manual[2].)

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