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Operational Amplifier Based Stretcher for Stripline Beam Position Monitors

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I. CHARACTERISTICS AND DETAILED DESCRIPTION

The stretcher amp was designed to accommodate existing instrumentation at the Boeing Free-Electron Laser (FEL) facility. The beam format for this system consists of two macropulses per second. Each macropulse contains several hundred micropulses separated by 462ns. Thus, 462ns is the upper limit to which the pulse can be stretched. The corresponding filter bandwidth would be about 3 Mhz.

In the stripline data acquisition system, one of six striplines is switched to a single transient digitizer channel. Tektronix TSS46 microwave relay switches are used. The output of the TSS46 goes into stretcher amps described here. The resulting signals are digitized by Analytek 2004S or 2008S transient digitizers. The transient digitizer timing is such that it samples the negative peak of the stripline signal from each micropulse. It's analogue bandwidth is 300Mhz. For good temperature stability and linearity, the stretcher bandwidth should be much less than 300MHz, say 30Mhz. This defines a lower limit to the pulse width.

30Mhz was chosen for the filter bandwidth. Making the bandwidth smaller, would have required more gain in the output amplifier. This would have resulted in too much noise at the output. Additionally, temperature drift and nonlinearity would also increase.

Figure 1 is a block diagram of the stretcher amplifier. An overall gain of 10.5 is provided by the last two operational amplifiers. A single CLC401 could have been used to accomplish this, however, the resulting reduced bandwidth would have produced a larger temperature drift coefficient. The stretching filter is a linear-phase, low-pass filter with a 30Mhz 3db point. It has an approximate constant time delay and gaussian roll off up to 60Mhz.

The filter reflects significant amounts of power in the pass band. If the signal cable is connected directly to the filter, signal power will travel back to the stripline. Here it will be reflected and may combine with the signal from a later micropulse. This will result in erroneous signal voltages. The CLC400 before the 30 Mhz filter has about a 5K input impedance. The 50 ohm resistor provides the needed broad-band termination.

Adding the CLC400 causes the stretcher amplifier to be unacceptably nonlinear because a lot of incoming signal power is outside the 200Mhz bandwidth of this amplifier. A Mini Circuits PLP-100 filter is used to eliminate most of the signal above 100Mhz. This results in a return loss of over 20db for the amplifier up to 60 Mhz. Reflected power which combines with a later beam signal is additionally attenuated 7db by the cable. This results in a signal-voltage error of less than .1% in subsequent signal pulses.

The time delay and gain of the stretcher amp were measured. The gain drops by 3.2db at 30Mhz, and about 13db by 60Mhz. This is consistent with the intended gaussian behavior of the filter. The time delay fluctuates by less than .5ns around 26ns up to 60Mhz.

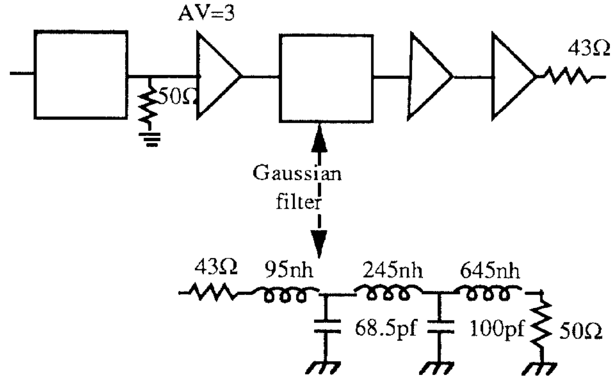

Figure 1. Stretcher amplifier.

The typical stretcher input signal consists of a negative leading lobe up to 900mv high and .9ns FWHM. This is followed by a 14ns positive tail with ringing and 1/10 the amplitude of the leading lobe. The output negative leading lobe is 9ns FWHM of about the same peak voltage as the input. The output positive trailing lobe has a peak value of about 3/4 the leading lobe, FWHM of about 10ns, and trails off in about 50ns.

II. NONLINEARITY MEASUREMENT

A Tektronix DSA 602 Digitizing Signal Analyzer was used to perform the linearity measurements. It was found that this oscilloscope had a nonlinear component to its response. Moreover, this nonlinearity depended on the signal shape being used. Thus, a direct input vs output measurement proved impractical. In the method described below, only output

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signals are observed by the oscilloscope. This assures that the signal shape is always the same. This also assures that frequencies involved in the measurement are kept an order of magnitude below the 1Ghz bandwidth imposed by the measurement setup.

Figure 2 shows the measurement setup. A pulser produces about 100v, 1ns FWHM, 10 pulses per second. This signal passes through the stripline test set. After a delay and attenuation, it serves as a trigger signal to the DSA 602. The stripline test set contains a standard stripline assembly of the type used in the Boeing FEL. One of the stripline outputs is connected to two variable attenuators in series. One of these attenuates in 1db step, the other in 10db steps. The signal then passes through 250 ft of RG-58. This is about the length of cable used with the FEL striplines to bring signals to the control room.

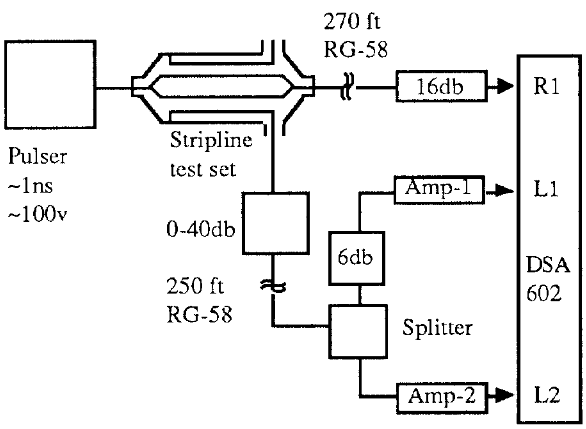

Figure 2. Nonlinearity measurement apparatus.

The signal is now split in two and fed into two amplifiers whose nonlinearity is to be measured. One stretcher amp gets about half the signal amplitude the other one does by introducing a 6db attenuator. If the two amplifier-plus-scope systems are linear, a plot of output 1 vs output 2 will be a straight line. If there is nonlinearity, the plot will no longer be a straight line. If the two channels are identical, a fit to this data could be used to determine the nonlinearity of the channels. If it is not assumed that the two channels are identical, an additional set of data is needed. This is done by moving the 6db attenuator from the amplifier 1 input to the amplifier 2 input.

Four sets of data were taken for four stretcher amplifiers. Their part numbers were SN001, SN002, SN003 and SN004. SN001 and SN002 were done as one pair. SN003 and SN004 were done as another pair. (All sets of data were taken with the same 11A72 plug-in module in the left slot of the DSA 602.)

A modification of the arrangement shown in figure 2 is used to measure the DSA602 nonlinearity. For this, everything is the same as for the amplifier measurements up to the end of the 250 ft. of RG-58. At this point, a stretcher amp is used to generate a wave form whose shape is the same as in the earlier measurements. A splitter and 6db attenuator are then used to generate signals for the L1 and L2 scope inputs. Two sets of data are taken with this arrangement, one for the 6db attenuator before L1, and one with the attenuator before L2.

As a first step in the data analysis, a linear fit is performed on the data (figure 3). All six sets of data display a complex nonlinearity. It consists of an oscillation around the straight-line fit. It is clearly due to the DSA602. The data involving the DSA602 only, are used to correct the data for the amplifiers. The result is then fitted with a linear-plus-quadratic function (figure 4).

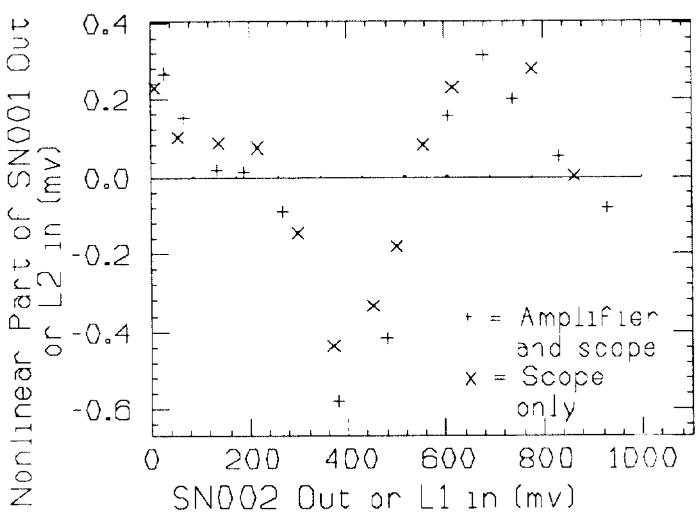

Figure 3. Example of nonlinear part of linear fit to the data. SN002 went to L1 and SN001 went to L2. The 6db attenuator was before SN001 or L2.

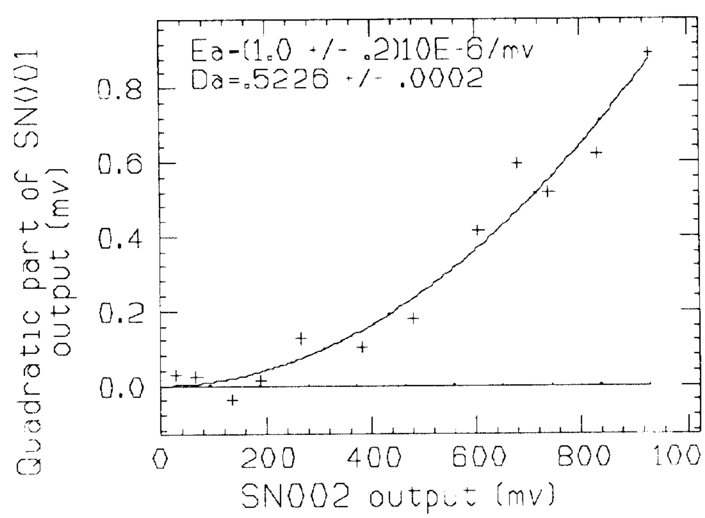

Figure 4. Example of corrected data. This shows the quadratic part of the fit of SN001 output ≈ .5 x SN002 output. The + are the data points and the solid curve is the quadratic part of the fit.

For the two amplifiers involved in a measurement, we write

$$v_{jo} = b_j v_{ji} + b^2_j C_j v^2_{ji} \quad (1)$$

Where j = 1 or 2, i and o refer to input and output. The fractional nonlinear part of the output is

$$\frac{b^2_j C_j v_{ji}}{v_{jo}} \approx C_j v_{ji} \quad (2)$$

Our objective now is to determine the C_j's

For the first of the two sets of data taken for each pair of amplifiers, $v_{2i} = f_a v_{1i}$. For the second set, $v_{1i} = f_b v_{2i}$. f_a and f_b are about .5, but are not exactly equal. Equation (1) can be inverted

$$v_{ji} = v_{jo}/b_j - C_j v^2_{jo}/b_j \quad (3)$$

Using this, one obtains

$$\begin{aligned} v_{2o} &= D_a v_{1o} + E_a v^2_{1o} \\ v_{1o} &= D_b v_{2o} + E_b v^2_{2o} \end{aligned} \quad (4)$$

The Ds and Es are expressed in terms of the Cs and fs. One can solve these to obtain

$$C_1 = \frac{D^2_a E_b + D_b E_a}{D_a D_b (D_a D_b - 1)} \quad C_2 = \frac{D^2_b E_a + D_a E_b}{D_a D_b (D_a D_b - 1)} \quad (5)$$

The Ds and Es are determined in the fitting procedure described earlier. One thus obtains Table 1. 900mv is the maximum recommended output voltage for these amplifiers. As can be seen from the table, uncorrected nonlinearities will contribute less than 1/3% error. If corrected, the error will be reduced to .05%.

TABLE 1

	C(X1E-6/mv)	% nonlinearity at 900mv output	Worst case error (mm) a =1cm
SN001	-2.8±.5	.25±.05	.006
SN002	-3.4±.7	.31±.06	.008
SN003	-1.0±.6	.09±.05	.002
SN004	-1.7±.5	.15±.05	.004

A beamline stripline unit supplies four signals. We refer to these by v_n and v_s for the x-direction and v_t and v_o for the y direction. The error associated with the nonlinear part of the amplifiers is

$$\Delta \frac{x}{a} = \frac{C_s v^2_{os} - C_n v^2_{on}}{v_{on} + v_{os} + v_{ot} + v_{ob}} \quad (6)$$

C_n and C_s are the nonlinearity coefficients associated with the n and s amplifiers and a is the beam-tube radius. The measured Cs are all negative. If we assume that this is true for all amplifiers of this kind, the worst error will occur if one of C_s or C_n is zero. Taking all v = 900mv and using the Cs from Table 1, one gets the last column in Table 1. If the nonlinearity is corrected, the remaining uncertainty due to the measurement error in the Cs will be .002mm for a 1cm beam-tube radius.

III. TEMPERATURE EFFECTS AND NOISE

The temperature dependence of gain and time delay are measured. The experimental setup is the same as in figure 6, except that no 6db attenuator is used and only one amplifier is used. The other amplifier is replaced by a direct connection from the splitter to the scope input. Thus, input and output waveforms are recorded simultaneously. The amplifier is placed in an oven and waveforms are recorded at 77.2 F and 117 F. The output voltage is at about 670mv. The ratio of the gain for the two temperatures is calculated. Also the change in time delay between the two temperatures was calculated. The average gain coefficient for the four amplifiers is -.0042%/C and the average time delay coefficient is 7.6ps/°C.

The amplifier noise is measured by putting the output of the amplifier into one of the scope channels, with no signal input to the amplifier. This is done with and without 250 ft of RG-58 connected to the amplifier input and with the amplifier input open, shorted and terminated in 50 ohms. The rms voltage feature of the DSA 602 in the measure mode is used to obtain the rms noise voltage. This is about 800 micro volts for all amplifiers under all conditions mentioned above. With the amplifier disconnected from the DSA 602, 200 micro volts of noise are observed, regardless of input termination. Thus, the amplifier output noise is taken as .8mv.