A PULSE-SIGNAL VIEWING SYSTEM FOR ACCELERATORS

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Summary

The operation of an accelerator requires that signals from various points about the machine be available for viewing in the control room. For the linear accelerator in the Los Alamos Meson Physics Facility (LAMPF), the cable-runs over which these signals must travel are up to 3000 ft in length. Consequently, a transmission system had to be developed which had a 10% to 90% rise time of 80 ns, an overshoot of < 0.5 dB, and a droop of < 0.5% for a 1-ns pulse. The necessary pre-emphasis filter for each cable run was designed by a computer program. This paper describes the system configuration, which provides for computer-controlled switching of 380 of the 660 signals and then outlines the computational procedure used in the filter design.

System Configuration

The Los Alamos Linear accelerator is organized into 10 sectors, each sector having from 4 to 7 modules, for a total of 95 modules. Signals from the various modules are gathered into their respective sectors for manual patching and/or automatic switching onto 4 high-quality, compensated and driven cables connected to the Central Control Room (CCR). Figure 1 shows that provisions have been made for patching up to 12 signals from each module. Signal switching and patching arrangements in CCR are shown in Fig. 2.

Of the 12 x 55 signals available through the system, the operator can select for simultaneous viewing any two of 32 x 10 signals via an automatic switching feature implemented through the control computer. The operator has only to specify via a pair of dials the particular signal desired and then press a button on the console to cause the trace to appear in the appropriate location on a dedicated oscilloscope. If more than two signals are needed simultaneously to diagnose a problem, the operator can bypass the final 20 x 2 multiplexer in CCR and can set up 20 pre-selected signals on the 10 x 2 trunk lines associated with the automatic switching network, thereby having available 20 simultaneous signals for viewing at the secondary racks in CCR. (See Fig. 2.) An additional 20 signals can be made available concurrently via the 10 x 2 trunk lines of the manual patching system. This array of signals provides the operator with a powerful diagnostic tool when the accelerator is performing marginally.

The cables from the module to the sector patch are RG-62, a low loss, high quality coax. The cables from sector to CCR are RG-22 B/U, a doubly shielded, twisted conductor twinax. RG-22 B/U cable provides a 60-dB reduction in electric field cross talk, compared to RG-8/U. In addition, the twisted conductors in the RG-22 B/U offer good rejection to low frequency magnetic field noise. A study made by Bell Telephone Laboratories shows that the peak noise must be at least 38 dB below the peak video signal (or any other band-limited signal of the same content) to be tolerable. Experimentally, the 38-dB figure appears to be quite sharply defined (i.e., 40 dB is quite acceptable, while 36 dB is very objectionable). For these reasons, RG-22 B/U was selected as a suitable cable for the long runs to CCR.

Analysis

The basic model of the video system for LAMPF consists of a two-section bridged-T filter and a run of twinaxial cable terminated in its characteristic impedance. A two-section filter was found to be required to meet the rise time and overshoot specifications. A fast driver is used with the filter at the transmitting end of the cable so that the input signal to the cable will be determined essentially by the filter characteristics. The model is indicated below:

\[ T(s) = \frac{K(s-Z_1)(s-Z_2)(s-Z_3)(s-Z_4)}{(s-P_1)(s-P_2)^2(s-P_3)} \]

This plot indicates that the filter has first-order zeros at \(-a_1\), \(-a_3\), \(-a_5\), and \(-a_7\). Also, it has: a first-order pole at \(-a_2\); a second-order pole at \(-a_6\); and a first-order pole at \(-a_6\). If the poles are represented as \(P_i\) and the zeros as \(Z_j\), the transfer function of the filter may be written as:

\[ T(s) = \frac{K(s-Z_1)(s-Z_2)(s-Z_3)(s-Z_4)}{(s-P_1)(s-P_2)^2(s-P_3)} \]

where \(K\) is a constant. This transfer function describes the smooth amplitude characteristic of the filter approximated by the Bode plot above. The zeros of the filter can be calculated from the pole locations and a knowledge of \(d_{B1}\) and \(d_{B2}\). \(T(s)\) may also be written in partial fraction form as follows. The \(C_i\)'s are constants.

\[ T(s) = K \left[ \frac{c_1}{(s-P_1)} + \frac{c_2}{(s-P_2)^2} + \frac{c_3}{(s-P_3)} + \frac{c_4}{(s-P_4)} \right] \]

Since the system specifications were given for the time domain step response, the step response, \(f(t)\), of the filter was found as follows:
\[ f(t) = \int_{0}^{t} L(t-s) ds \]

\[ f(t) = \begin{cases} 
\frac{C_1 P_1 t}{F_1} e^{(-P_1 t)} + \frac{C_2 P_2 t}{F_2^2} e^{(P_2 t - 1)} + \frac{C_3}{F_2^3} e^{(-P_2 t)} + \frac{C_4 P_3 t}{F_3} e^{(P_3 t - 1)} \\
+ \frac{C_5 P_1 t}{F_1} e^{(-P_1 t)} + \frac{C_6 P_2 t}{F_2^2} e^{(P_2 t - 1)} + \frac{C_7 P_3 t}{F_3} e^{(P_3 t - 1)} 
\end{cases} \]

K was calculated to normalize the filter step response by letting \( f(0^+) = 1 \).

\[ K = \frac{1}{\sqrt{C_2^w C_3^f}} \]

The step response of a length \( x_0 \) of coaxial cable with a loss factor \( b \) is given by:

\[ G(t) = \frac{bx}{\sqrt{\pi t}} \]

where \( t \) is time-measured from the time at which the output voltage begins to change and erfc is the complementary error function. To find the impulse response of the cable, the derivative of \( G(t) \) with respect to \( t \) is calculated.

\[ g(t) = \frac{dG(t)}{dt} = \frac{bx}{t^{3/2} e^{(-bx^2/2)}} \]

Finally, the step response of the system, \( r(t) \), is given by the convolution of \( f(t) \) and \( g(t) \).

\[ r(t) = f(t) * g(t) \]

\[ r(t) - K \left\{ \begin{align*} 
&= \frac{C_1 P_1 t}{F_1} e^{(-P_1 t)} + \frac{C_2 P_2 t}{F_2^2} e^{(P_2 t - 1)} + \frac{C_3}{F_2^3} e^{(-P_2 t)} + \frac{C_4 P_3 t}{F_3} e^{(P_3 t - 1)} \\
&+ \frac{C_5 P_1 t}{F_1} e^{(-P_1 t)} + \frac{C_6 P_2 t}{F_2^2} e^{(P_2 t - 1)} + \frac{C_7 P_3 t}{F_3} e^{(P_3 t - 1)} 
\end{align*} \right\} \]

\[ + \left[ \frac{bx^2}{(t-T)^{3/2} \sqrt{\pi t}} \right] d\tau \]

The argument \( t \) is the time measured relative to the time at which the voltage at the output of the cable begins to change.

Results

The analysis above was used as the basis of a computer program which designs the two-section bridged-T filters to specification. The program provides the following outputs:

(a) The amount of compensation and the frequency range of the compensation.

(b) The maximum and minimum cable lengths allowable for a given filter.

(c) The value of the normalized response at several values of time. This information verifies that the rise time specification is met and shows the maximum value of the response and the dB overshoot for each 25-ft increment in the allowable range of cable lengths.

(d) A set of component values for the filter.

The results of the analysis and the output of the program were verified in the laboratory by constructing a filter based on the components calculated for a cable run of 2040 ft. The only deviation from theory was a trim required by one capacitor to compensate for the error induced by non-ideal components. The terminated cable showed a rise time of \( 55 \) ns and an overshoot of \( 0.13 \) dB, well within the design specifications.

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Reference