CROSSING HIGH-VOLTAGE INTERFACES WITH LARGE BANDWIDTH SIGNALS*

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Summary

In connection with a 50-kV modulator development, three methods of crossing the high-voltage interfaces at a 1-MHz bandwidth are being developed.

The first system uses a pulse transformer driven from ground by solid-state electronics. The transformer requires special design to obtain a very short (≈ 500 ns) risetime combined with the ability to maintain a 1000-μs, 200-V pulse with negligible droop.

The second system is an amplitude-modulated rf carrier operating at 5 MHz. The interface is crossed with an untuned toroidal rf transformer. Increased bandwidth is obtained by placing the carrier at the lower edge of the passband and operating in the single sideband full carrier mode. The signal is demodulated with a balanced diode detector having a peak output of +200 V and good linearity.

The third method uses a Hewlett-Packard HPA-4309 electro-optical isolator with solid-state amplifier on the high-voltage side. The intrinsic bandwidth of the isolator unit is ~ 10 MHz. With suitable amplifiers to bring the pulse up to +200-V peak, the bandwidth is ~ 2 MHz. Because the interface is crossed at a very low level reaching an adequate signal-to-noise ratio has presented special problems.

All three systems should be useful on a wide variety of high-voltage laboratory machines; each has special advantages depending on the particular application.

Description of Experiment and Results

The problem of transmitting a control signal between ground and circuitry floating at high potential is one frequently encountered in accelerator design.

At the LASL Meson Facility, the problem has been to supply an amplitude control signal to the floating deck of a 50-kV pulse modulator. The output signal on the high-voltage side of the interface must have a bandwidth of 1 MHz, an amplitude variable from 20 to 140 V, and a pulse length of 1000 μs.

Three solutions have been investigated: a direct pulse transformer, an amplitude-modulated 5-MHz rf link, and an electro-optical isolator (light-pipe) assembly.

The pulse transformer interface unit is shown in Fig. 1. The unit consists of a pulse amplifier to bring the +10-V input pulse up to 140 V at 10 A to drive the 1:1 pulse transformer. The pulse amplifier uses only three transistors along with the power supply and passive components. This unit is very simple and potentially highly reliable.

The bandpass characteristics are shown in Fig. 2. The -3 dB point is about 850 kHz and there is +6 dB of peaking at 600 kHz. The large bump beginning at 1500 kHz is due to the characteristics of the pulse transformer itself as shown in Fig. 3. The sharp nulls in the response are due to series resonances of the stray capacity with the leakage inductance and are to be expected in any large pulse transformer. Referring again to Fig. 2, the effect of these resonances is to cause a very sharp roll-off, 30 dB/octave, which, if phase shift is important, would reduce the usable bandwidth considerably. Another difficulty with the pulse transformer is the primary-to-secondary capacity which is > 200 pF. This can be very troublesome in some circuits, particularly in a floating deck modulator where this capacity is effectively in parallel with the switch tube input capacity. The large signal response is very linear with a maximum deviation of < 0.5% over its range as shown in Fig. 4.

Figures 5A and 5B show the rf interface unit. It consists of a 5-MHz oscillator; a 10-W, screen-modulated, rf amplifier; an insulated, untuned ferrite rf transformer which actually crosses the high-voltage interface; and a detector unit. This unit contains three times as many active elements as the pulse transformer crossing scheme and would be correspondingly less reliable; however, the transfer characteristics are better with the -3 dB point at 1100 kHz, 1 dB of peaking at 650 kHz, and a slower roll-off (Fig. 6). The roll-off is still quite rapid, 21 dB/octave. The large signal transfer characteristic, Fig. 7, is the least linear of the three with a deviation from linearity of about ± 2%. This is primarily due to the characteristics of the screen grid which will vary from one tube type to another and with the method of modulation. Control grid modulation is more linear but it adds the tuned circuit of the driver stage to the output characteristics which reduces the bandwidth. The capacity introduced by the coupling transformer is small, ≈ 11 pF, and could be reduced further with an air core design.

An attempt was made to produce a transistorized model but it was found that the bandpass characteristics were very much a function of the pulse amplitude and the large signal voltage transfer characteristic was very non-linear. The transistor version was not suitable for a closed-loop application and was abandoned, at least for the present. A properly designed transistorized unit would be very desirable because it should be much more reliable and less complex than the tube version.

The third unit is shown in Fig. 8. It is built around a Hewlett-Packard Associates HPA-4309

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electro-optical isolator unit. The 4309 consists of a source diode, a fiber optic link, and a receptor diode. The isolator has been hi-potted to 55 kV at 7000 ft without failure. The frequency response characteristics of the isolator and the high-gain amplifier are shown in Fig. 9. The roll-off is smooth with no peaking at 8 dB/octave and the -3 dB point is 1.8 MHz. The unit is very satisfactory from a performance standpoint. The main difficulty with this unit is the very low level at which the signal reaches the deck, $\approx$ 1 mV. This requires a very high-gain amplifier on the deck which is quite susceptible to noise pickup and false triggering. The amplifier is housed in a double shielded inclosure which reduces the pickup, however, the unit is still quite sensitive. In an environment where there are frequent discharges or high-voltage transients, the light-pipe interface unit may be unsuitable.

The isolation provided by the unit is, of course, very good. The stray capacity is much less than 1 pF and the resistance is in the thousands of megohms; also, the unit is truly unilateral. The large signal response is shown in Fig. 10 and is very linear.

Each of the three units has special advantages in different situations.

If bandwidth is not all-important, the pulse transformer is the simplest and most economical. The bandwidth limit for a large transformer with conventional insulation at 50 kV is about 2 MHz. In addition, very large output pulses, many kV, are readily possible with a reasonable size of transformer. The size of the transformer is dictated by the volt-time product of the pulse and by the voltage insulation. Some care must be exercised when using the pulse transformer with transistorized drivers. Because the transformer is completely bilateral, transients applied to the secondary will appear in the primary to the possible detriment of the driving transistors. Also, on the trailing edge of the pulse, there will be a large negative spike which generally must be clipped.

For those applications where bandwidth is all-important and the environment is reasonably quiet, the light-pipe assembly is definitely the best. By selecting the best diodes, it should be possible to attain a bandwidth of 30 MHz. The principal drawback of a really fast unit is that the output voltage would be limited to 50-60 V since most transistors for over 100 V are not particularly fast. The fiber optic link is also quite well suited for very high-voltage equipment because it can be extended to almost any length with negligible increase in the light path attenuation.

The rf link represents a compromise between the pulse transformer and the light pipe. The bandwidth is good, 10 MHz should be attainable with an increase in the carrier frequency, and output pulses of several kV can be obtained. The rf link, like the pulse transformer, puts most of the hardware at ground potential rather than on the deck. This is a very real advantage from a maintenance point of view, especially if the high-voltage equipment is in a pressure vessel or an oil tank. It is somewhat easier to insulate an rf transformer than a pulse transformer and the upper voltage limit should be correspondingly higher.

An additional advantage of the rf link and the light pipe is that the response extends down to dc. So the units are perfectly usable for dc level control as well as transient signals.

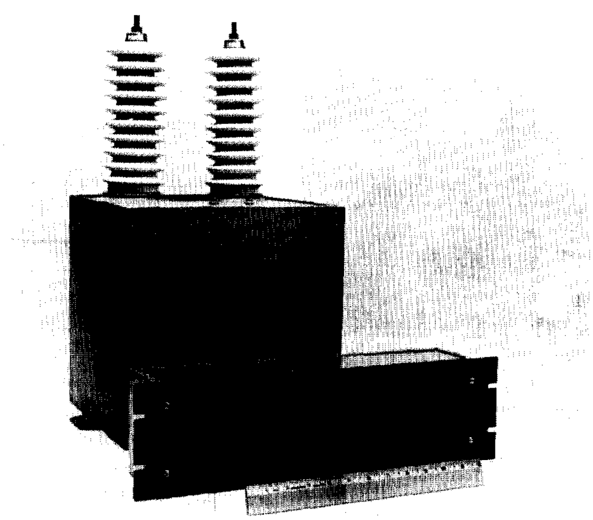

Fig. 1. Pulse transformer and pulse amplifier.

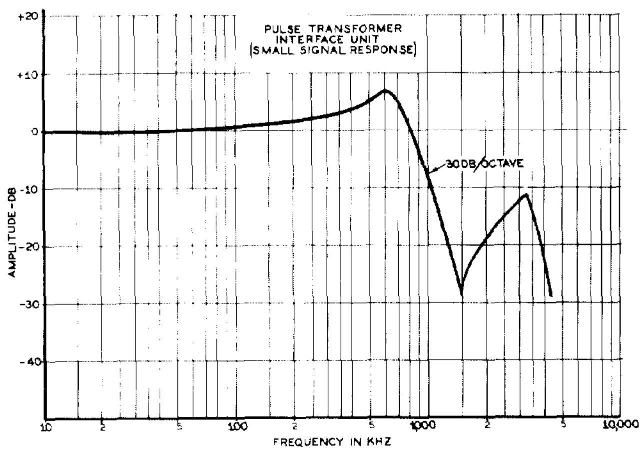

Fig. 2. Pulse transformer interface unit, small signal response.

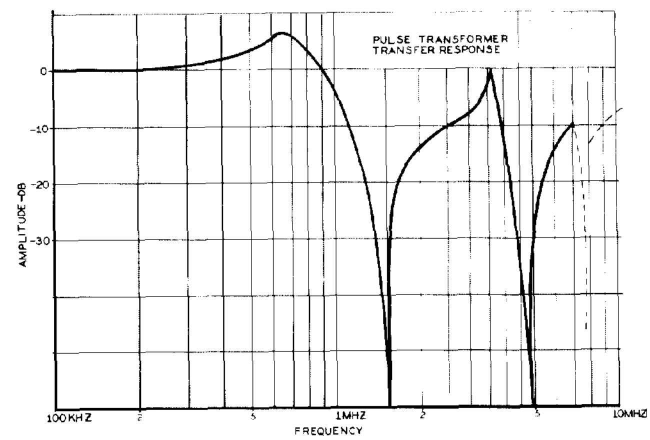

Fig. 3. Pulse transformer transfer response.

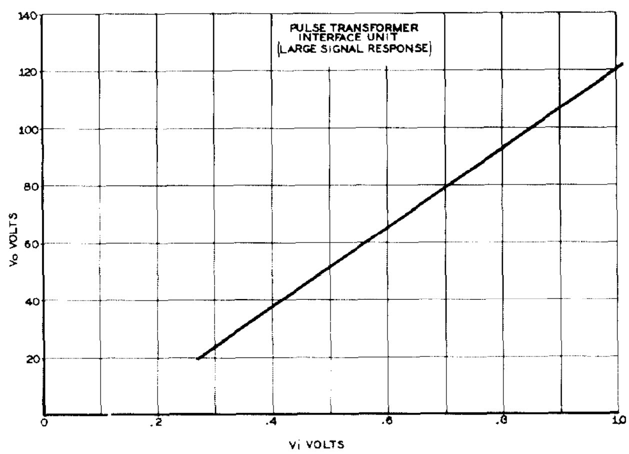

Fig. 4. Pulse transformer interface unit, large signal response.

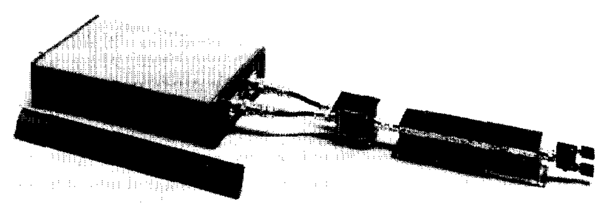

Fig. 5a. RF transformer and detector unit.

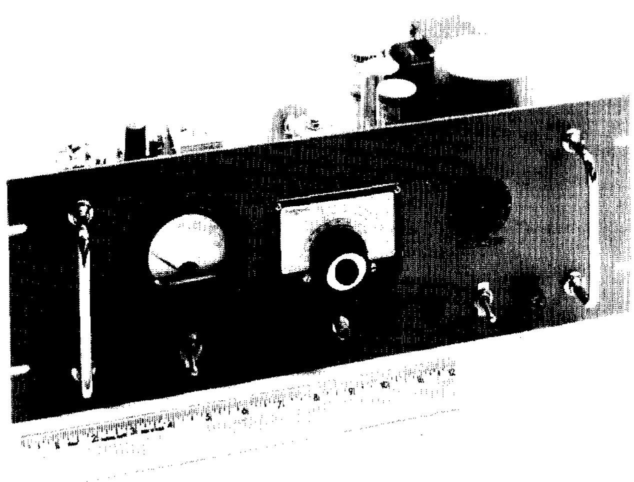

Fig. 5b. 5-MHz rf generator.

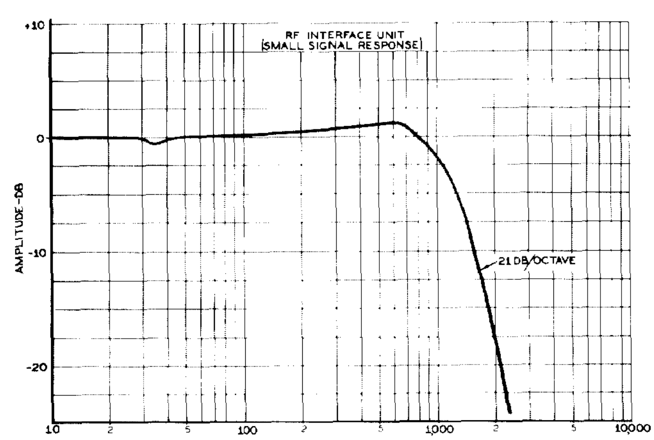

Fig. 6. RF interface unit, small signal response.

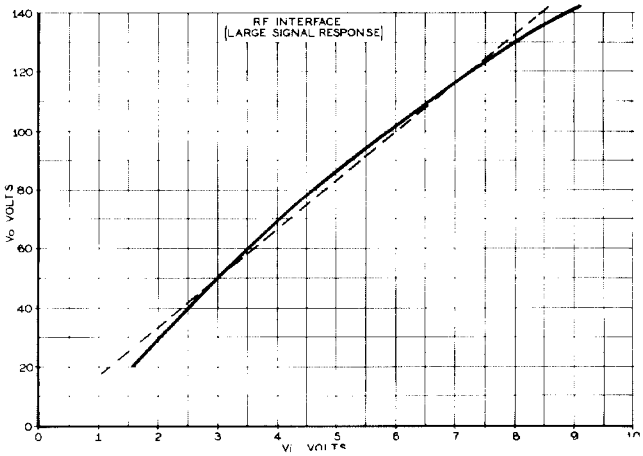

Fig. 7. RF interface unit, large signal response.

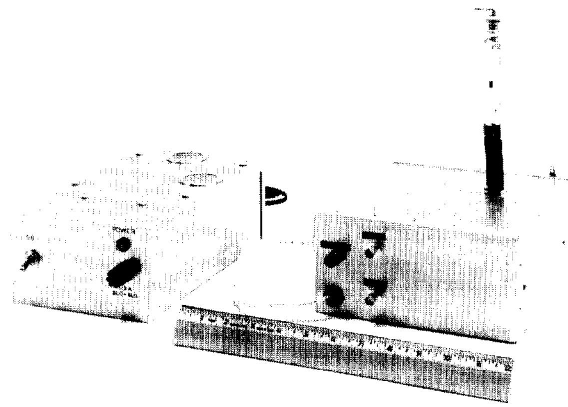

Fig. 8. Electro-optical isolator interface unit.

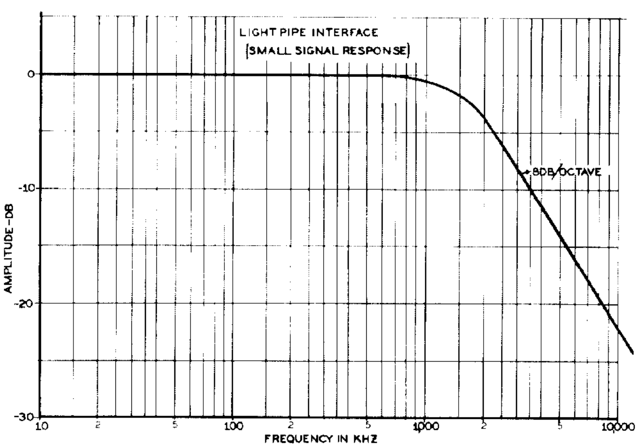

Fig. 9. Light-pipe interface unit, small signal response.

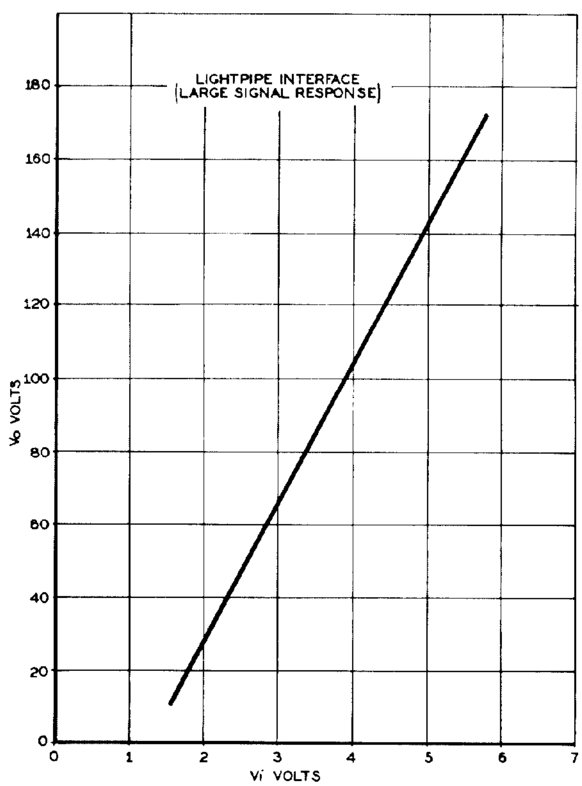

Fig. 10. Light-pipe interface unit, large signal response.