GEPP-TIS-1188
UC-706

Pinellas Plant

U.S. Department of Energy

Technical Information Series

Test System Electronic Reference Signal Injection

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Principal Engineer
Specialty Equipment

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June 1991

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For the U. S. Department of Energy
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TEST SYSTEM ELECTRONIC REFERENCE SIGNAL INJECTION

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By GE Neutron Devices
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ABSTRACT

A concept for a method of injecting reference signals into waveform monitoring systems which has negligible effect on measurement accuracy is presented. Equations are provided which allow a test system designer to tailor the injection design to meet specific requirements. Examples of typical use are included.

The signal injection concept presented has been successfully employed at GE Neutron Devices. It has been incorporated in quality assurance test systems to provide a fiducial or time zero reference marker for time correlation of waveforms monitored by independent digital oscilloscopes. It has also been found to be useful for the injection of simulated product waveforms employed for automatic test system calibration and/or operational verification just prior to product testing.

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INTRODUCTION

At times, it may be desirable to inject reference signals into electronic waveform monitoring systems to serve the purpose of: timing reference marks, system calibration/continuity, verification, distortion, or system degradation measurement. Effective injection requires that the injecting source be as transparent as possible so that it will produce minimum distortion and place the minimum possible load on the monitoring system with which it is being employed. This report describes a high-source impedance injection generator which may be employed to meet this need.

HIGH IMPEDANCE

High impedance is a relative term--high impedance with respect to what? To clarify, recognize that the injection generator will provide a load to the monitoring system. The loading that does occur must fall within acceptable limits based on monitoring accuracy requirements or the ability to compensate for the effect. An approach is to allow the loading effect to be no greater than one-tenth the accuracy requirements; that is:

$$\% \text{ Loading Effect} \leq (0.1) \times \% \text{ System Accuracy} \qquad (1)$$

INJECTION GENERATOR

The injection generator may have either of two equivalent forms--it may be a Thevenin or a Norton generator. A diagram of both forms is shown in Figure 1. For the development of the particular injection generator being suggested, the Norton generator form is the more convenient to use. A practical circuit illustrating the employment of a Norton generator injection source is shown in Figure 2.

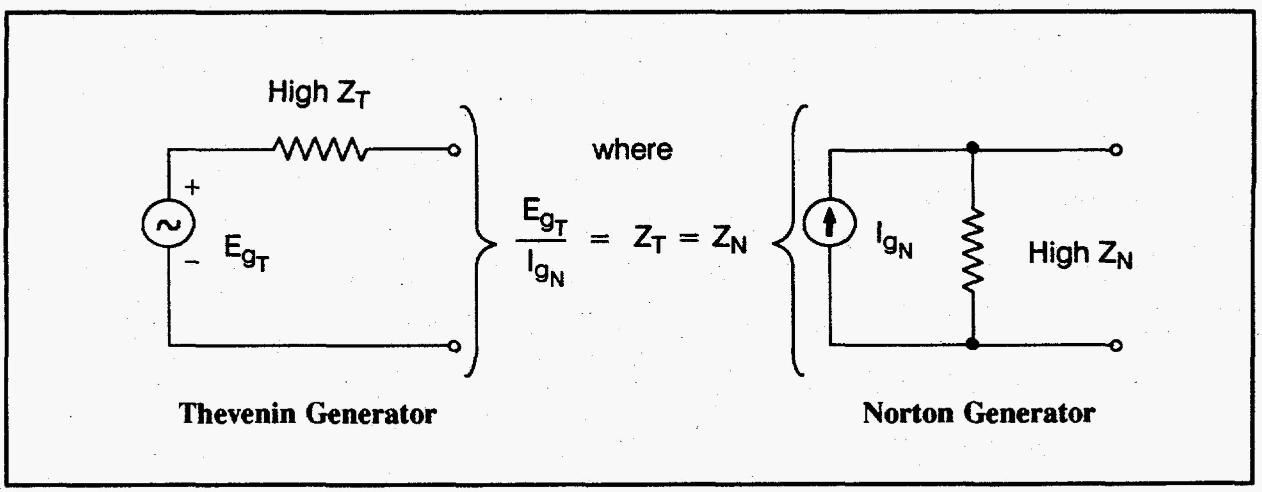


Figure 1. Injection Generator Equivalent Forms

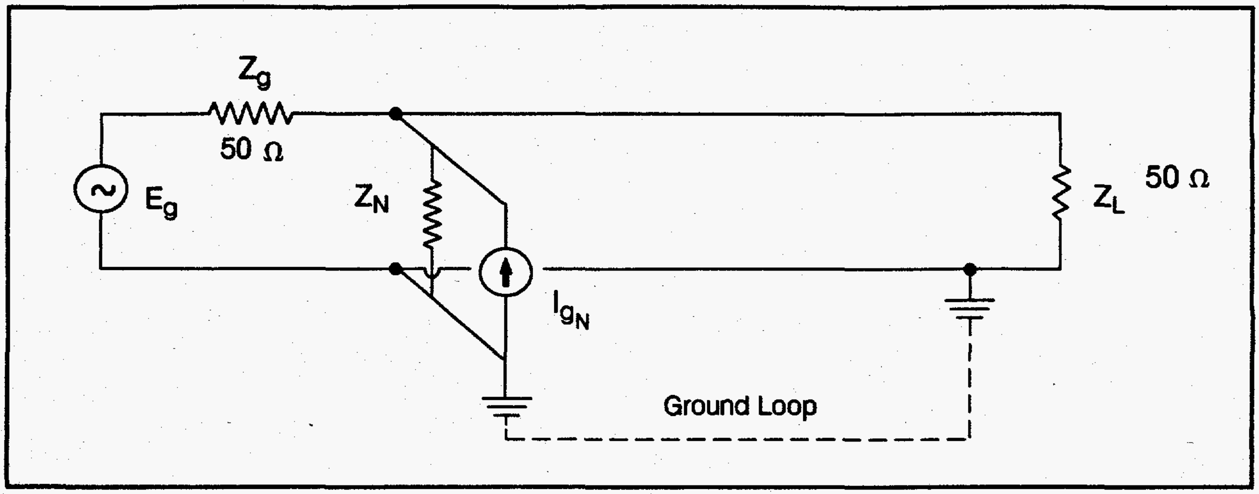


Figure 2. Norton Generator Injection Source

To meet the requirements of equation 1 with regard to loading, if the monitoring system accuracy requirement is 1%:

$$Z_N = \left(\frac{1}{\frac{1}{Z_g} + \frac{1}{Z_L}} \right) \left(\frac{100}{\%\ \text{Accuracy}} \right) \times 10 \qquad (2)$$

$$Z_N = 25{,}000\ \Omega$$

TRANSFORMER COUPLING, GROUND LOOPS, SIGNAL SUMMING

As can be seen in Figure 2, there is a ground loop caused by the injection generator. One mechanism employed to eliminate or minimize its effect is transformer coupling in conjunction with a current-balancing choke. This mechanism is illustrated in Figure 3 .

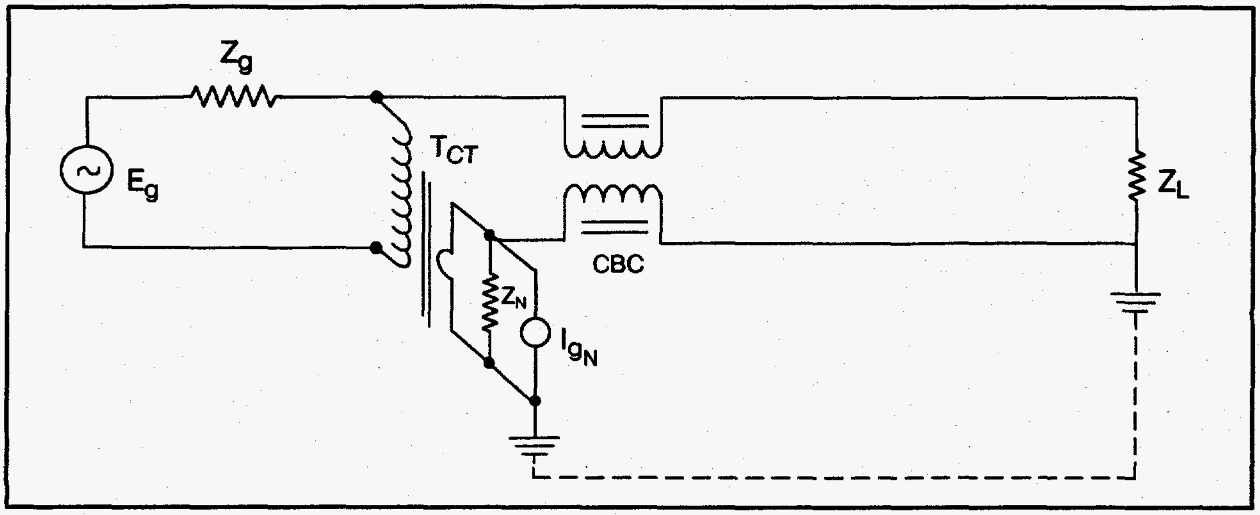


Figure 3. Transformer Coupling and Current-Balancing Choke Ground Loop-Isolation

Transformer coupling has an added advantage, as it may be employed both as an impedance multiplier and an injected-signal summing device. For the case of impedance multiplication:

$$Z_{OUT_S} = Z_{IN_P}\left(\frac{N_s}{N_p}\right)^2 \tag{3}$$

where N_s/N_p is the turns ratio. Equation 2 may be expanded to take advantage of this multiplying effect:

$$Z_N \geq \left(\frac{1}{\frac{1}{Z_g} + \frac{1}{Z_L}}\right)\left(\frac{100}{\%\ \text{Accuracy}}\right)\left(\frac{N_s}{N_p}\right)^2 \times 10 \tag{4}$$

If equation 4 is rearranged, the ideal transformer turns ratio may be determined when Z_N, Z_g, Z_L, and Accuracy are given:

$$\frac{N_s}{N_p} \geq Z_N\left(\frac{1}{Z_g} + \frac{1}{Z_L}\right)\left(\frac{\%\ \text{Accuracy}}{100}\right) \times \frac{1}{10} \tag{5}$$

Injection signal summing may be accomplished by the addition of primary windings (Figure 4). Of course, one must now take into account the additional generator impedances loading on the monitor circuit. Their additive effect would take the form:

$$Z_{TOTAL} = \left(\frac{1}{\frac{1}{Z_{N1}} + \frac{1}{Z_{N2}} + \frac{1}{Z_{N3}}}\right) \tag{6}$$

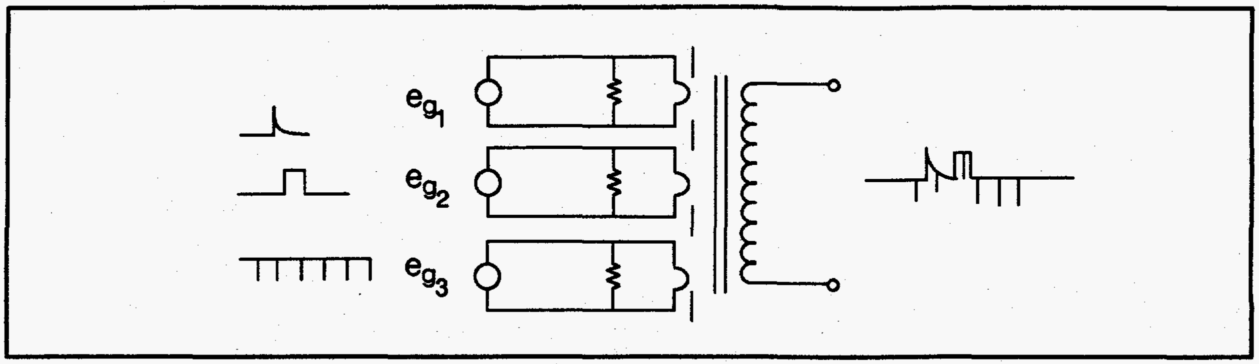


Figure 4. Example of Injection Signal Summing

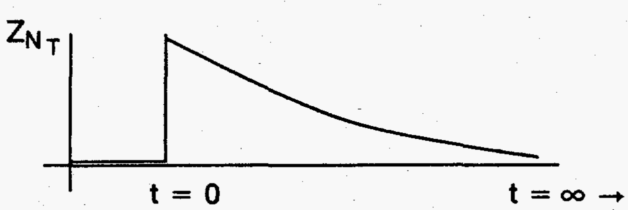
Coupling Transformer Design

The employment of a coupling transformer adds a complication. The injection generator's impedance becomes time dependent. This dependance is easily visualized in the La Place or "s" domain (neglecting leakage inductance and distributed capacitance) as:

$$Z_S \text{ Loading} = \left(\frac{N_S}{N_P}\right)^2 \left(\frac{1}{\dfrac{1}{Z_{N\ TOTAL}} + \dfrac{1}{SL_{S\,MAGNETIZING}}}\right) \tag{7}$$

If a step function (a worst-case condition) of voltage were applied to the injection generators output terminals, the generators impedance would have the time domain form:

$$Z_N = Z_{N\ TOTAL}\ \epsilon^{-\left(\frac{Z_N}{L_{SM}}\right)t} \tag{8}$$



The impedances include the effect of the transformer windings turns ratios. This impedance time change distorts the monitored signal. Here again, with appropriate design, the distortion is minimized. Reconfiguring equation 8 in the series form:

$$Z_N = Z_{N\ TOTAL}\left[\sum_{n\ \ 0\rightarrow\infty}\left(\frac{x}{n_1!}\right)^n\right] \quad \text{where } x = -\frac{Z_T}{L_{SM}} \tag{9}$$

or

$$Z_N = Z_{N\ TOTAL}\left[1 - \frac{Z_T t}{L_{SM}(1!)} + \left(\frac{Z_T t}{L_{SM}}\right)\frac{2_1}{(2!)} - \left(\frac{Z_T t}{L_{SM}}\right)\frac{3_1}{(3!)} \cdots\right] \tag{10}$$

Now, selecting only the first two terms of the series that is truncating in equation 10, provides the following equation:

$$Z_N = Z_{N\ TOTAL}\left(1 - \frac{Z_T t}{L_{SM}(1!)}\right) \tag{11}$$

Figure 5 depicts a comparison of a general plot of equations 8 and 11.

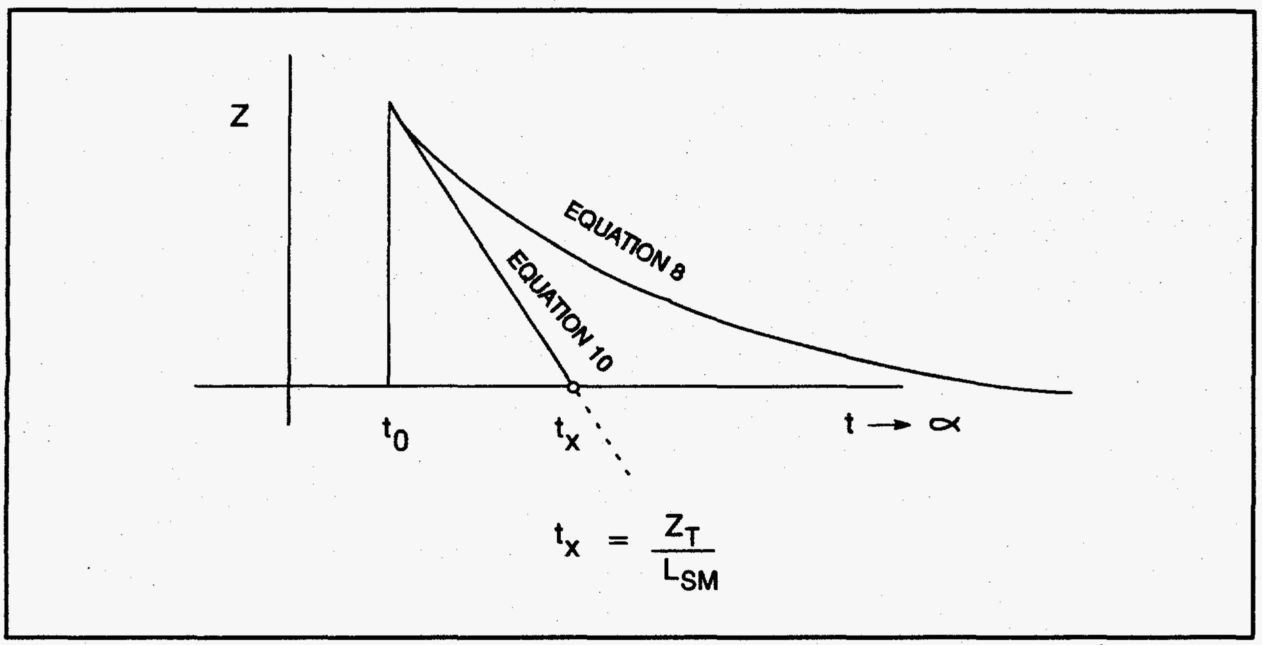


Figure 5. Comparison of Real and Truncated Equation Impedance Decay Rates

Notice that equation 10's impedance/time induced distortion is always worse, but of simpler form. That being the case, it will be employed to determine the value of L_{SM} required for a given or allowed distortion (or transformer-induced signal droop).

Rewriting equation 10 as:

$$\frac{Z}{Z_N} = 1 - \left(\frac{Z_T t}{L_{SM}}\right) t_x \tag{12}$$

solving for L_{SM}:

$$L_{SM} = \left[\frac{Z_{N_T}}{\left(1 - \frac{Z}{Z_{N_T}}\right)}\right] t_x \qquad (13)$$

where t_x is the time over which the allowed distortion must be maintained. If it is assumed that z is equal to the allowed injection generator loading, equation 13 becomes:

$$L_{SM} = \left[\frac{Z_{N_T}}{1 - \dfrac{100}{Z_{N_T}\left(\frac{1}{Z_g} + \frac{1}{Z_L}\right)\left(\%\ \text{Accuracy}\right)\left(\frac{N_p}{N_s}\right)^2\left(\frac{1}{10}\right)}}\right] t_x \qquad (14)$$

To ensure that sufficient core material is available to support the injection generator and monitor systems, secondary voltage for the proper period of time should be employed:

$$VT = \frac{6.45\ BAN_sS}{10^8} \qquad (15)$$

where: V = Volts
t = Time of view of monitored signal in microseconds
B = FLUX density (for unbias core MO per M : 3000) ϕ/N^2
A = Cross-sectional area of the core in inches^2
N = Secondary turns
S = Core stacking factor (Core material area/Total core area)

Injection Generator Transformer

The recommended form of the injector's transformer, based on the author's experience, is a toroidal tape, wound transformer employing 1- to 2-mil thick molybdenum permalloy. A loosely wound single- to two-turn primary is preferred with a tightly wound multi-turn secondary. This type of configuration produces low secondary leakage inductance and distributed capacitance, and relatively high values of these parameters in the primary minimizing back-signal coupling. In fact, the ideal design appears to be the single-turn, primary current transformer employed in Current Viewing Transformers (CVTs). Several use configurations are illustrated in Figures 6 through 9.

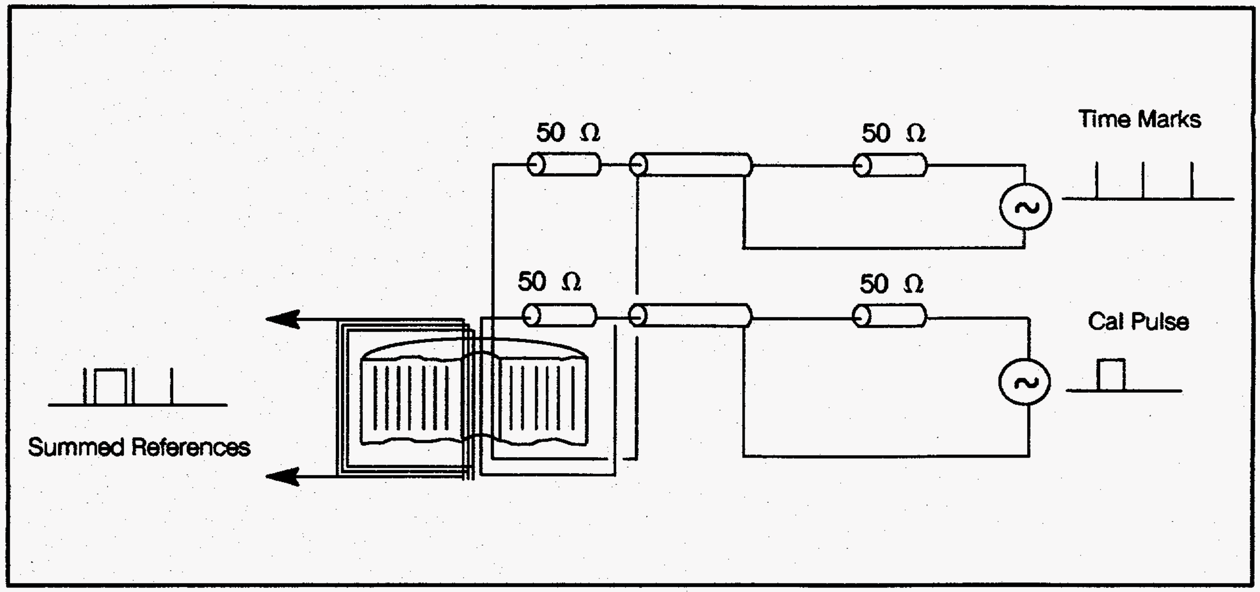


Figure 6. Summing Reference Signals Employing a Current Transformer

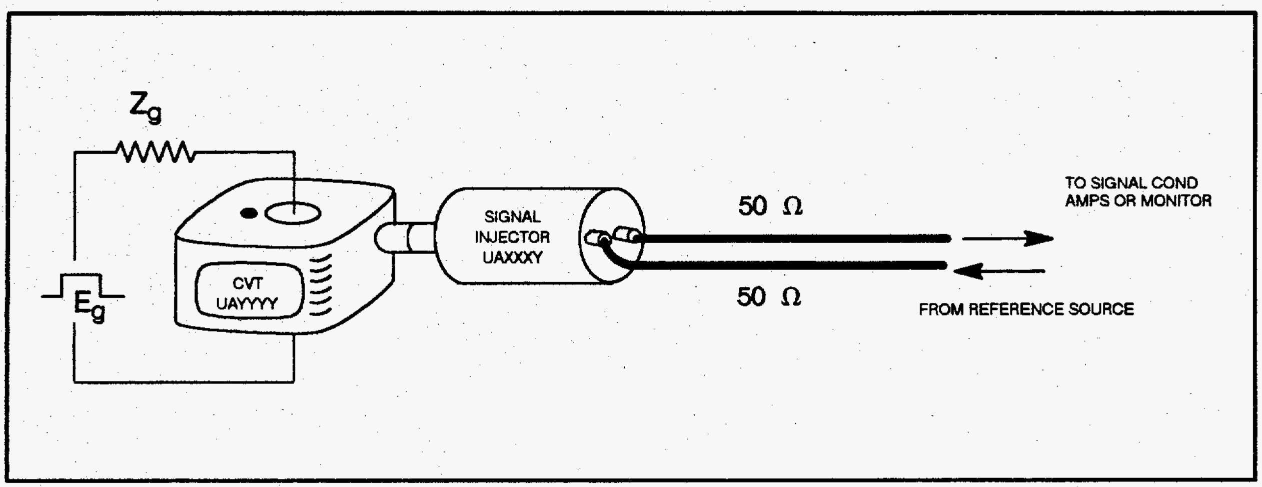


Figure 7. Signal Injector and Current Viewing Transformer Combination

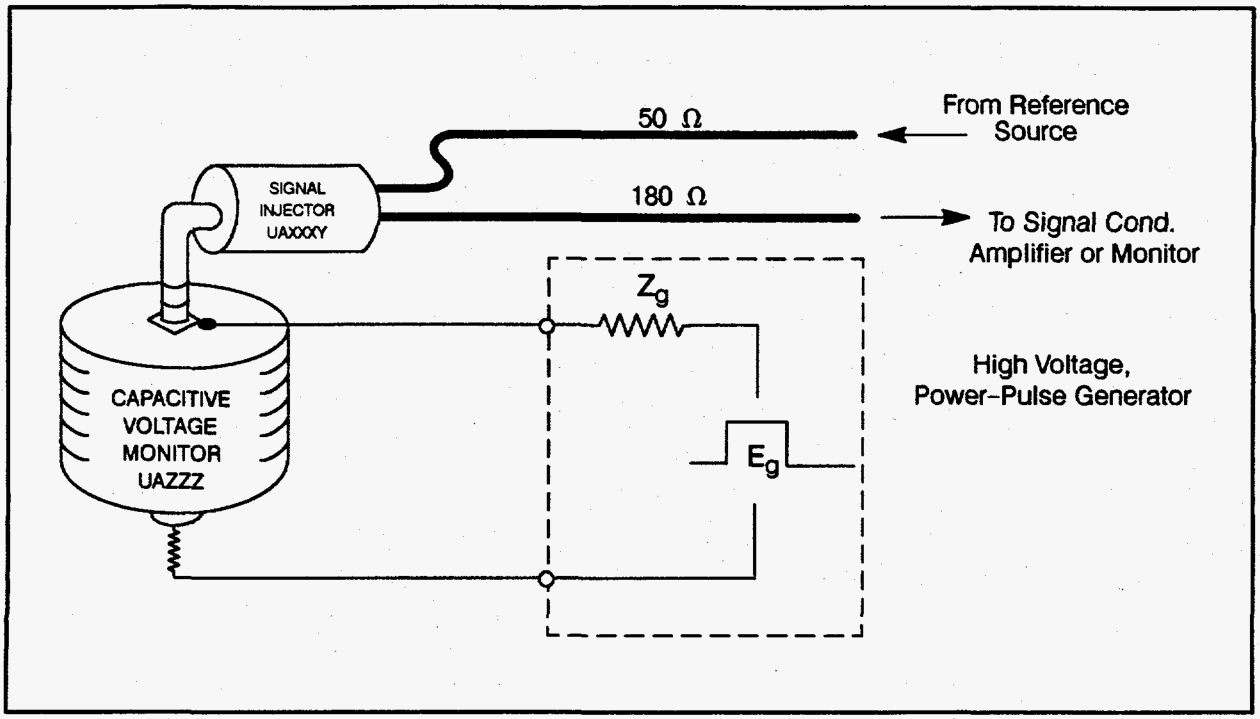


Figure 8. Signal Injector Employed With Capacitive Voltage Monitor

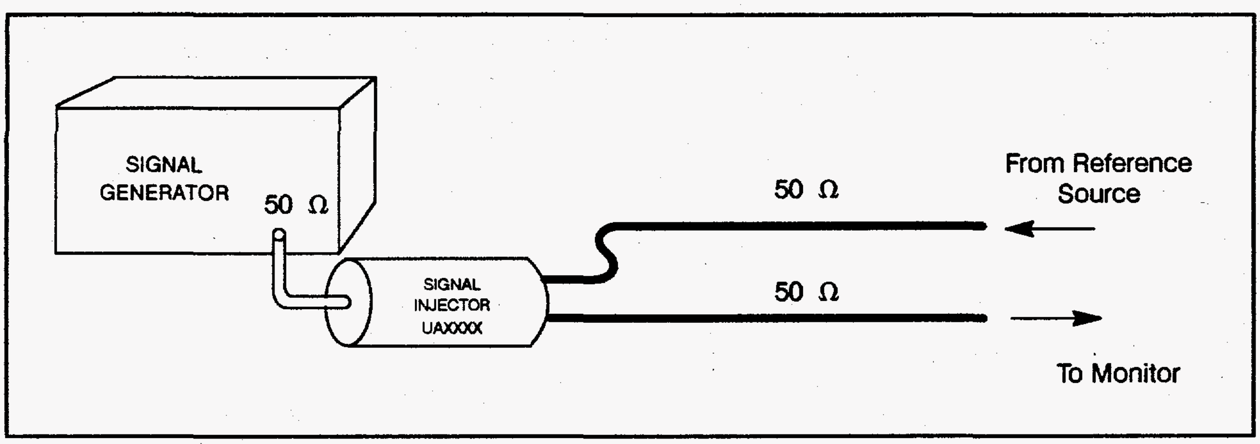


Figure 9. Signal Injector Employed With Electronic Instrument

SUMMARY

The signal injection concept presented has been successfully employed at GE Neutron Devices. It has been incorporated in quality assurance test systems to provide a fiducial or time zero reference marker for time correlation of waveforms monitored by independent digital oscilloscopes. It has also been found to be useful for the injection of simulated product waveforms employed for automatic test system calibration and/or operational verification just prior to product testing.

ACKNOWLEDGMENTS

Equipment designer H. Bellairs is recognized for the first employment of this concept in an automated test system. Sincere appreciation is extended to equipment designer K. Allen and technician M. Roth for the fortitude they displayed in bringing the first use of this concept to fruition.

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