IV-5. FILTER REQUIREMENTS FOR NANOSECOND DIODE SWITCHING

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Abstract. In some applications of diode switches, such as in a switch-protected radar receiver, high speed switching is required in conjunction with a high degree of suppression of switching transients appearing at the rf terminals of the switch. The minimum switching time of a series or shunt diode switch is derived to be $1.24/f_0$, where f_0 is the rf frequency being switched. The suppression of switching transients is derived, and it is found that suppression can be increased at the cost of increased filter complexity and switching time above the theoretical minimum. An example is presented utilizing the derived relationships.

Introduction. A practical diode switch must have some circuit arrangement which prevents rf power from leaking out the modulation input port and suppresses the modulation voltage components appearing at the rf port. For fast switching it is necessary to separate the spectrum of the modulation pulse from the spectrum of the modulated rf power. Multiple diodes in a symmetrical bridge-type switch (such as that used in sampling oscilloscopes) can provide 30 to 50 dB suppression of modulation power at the rf port. In some systems such as a diode switch-protected radar receiver, a higher degree of suppression of modulation power is required, and it is not convenient to use a symmetrical bridge-type switch. The necessary decoupling may be obtained using filters to separate the spectral components. High modulation suppression is obtained at the expense of increased filter complexity and switching time above a theoretical minimum. mum.

The problem of suppressing the transients is illustrated in Figure 1. The switching transients, illustrated by the dashed curves on the lower plot, can cause the same receiver saturation and consequent dead time that the switch is supposed to eliminate.

Theoretical Minimum Rise Time. The required filters for a diode switch[1] are illustrated in Figure 2. The low-pass filter must pass the essential spectral components of the modulator pulse. Since the low-pass filter has a finite 3-dB bandwidth, BW, it will cut off some of the infinite spectrum of a zero rise-time pulse giving it 10% to 90% switching time given by:

$$\tau_F = 0.44 / BW \qquad (1)$$

The high-pass filters must pass the spectral components of the modulated carrier or further deteriorate switching times. Ideally the filters should be constant time delay filters to prevent "ringing".

Assuming that the difference between the carrier frequency and the cutoff frequency of the high-pass filters is equal to the bandwidth of the low-pass filter, then, because rise times add as the sum of their squares, the switching times of the modulated carrier is given by:

$$\tau = \frac{0.44\sqrt{2}}{BW} = \frac{0.62}{BW} \quad (2)$$

Since the spectra have to be separated, the best arrangement of filters from a switching time point of view is to have their 3-dB frequencies coincide at $f_o/2$; thus the minimum switching time becomes:

$$\tau_{min} = \frac{0.62}{f_o/2} = \frac{1.24}{f_o} \quad (3)$$

This equation indicates that the lowest switching times that could be impressed using filters on a 1 GHz carrier is 1.24 nsec, and on a 10 GHz carrier is 0.124 nsec.

Modulation suppression. To suppress the modulation voltage appearing at the rf port of the diode switch, the 3-dB frequencies of the low-pass and high-pass filters are separated as illustrated in Figure 3. Assuming the diode provides no significant pulse shaping, then the attenuation of spectral components passing through the combination of low-pass and high-pass filter would be as illustrated in Figure 4. The attenuations assumed are reasonable approximations for maximally flat filters in which n is the number of elements in the low-pass prototype of each filter. The entire curve would be higher for Chebychev filters and lower for constant time delay filters. Chebychev filters, however, cause too much ringing when used with pulses, and constant time delay filters are difficult to fabricate in TEM transmission lines.

The transient of a step voltage, A, when attenuated as in Figure 4, is a wave packet with a maximum peak voltage, V_o max. The suppression, S, is defined by:

$$S = 20 \log \frac{A}{V_{o\,max}} \quad (4)$$

For one-element filters LaPlace transforms can be used to determine the suppression which is given by:

$$S_1 = 20 \log \left[\left(2\frac{f_2}{f_1} + 1 - \sqrt{(2\frac{f_2}{f_1})^2 + 1} \right) \left(\frac{2\frac{f_2}{f_1} + 1 + \sqrt{(2\frac{f_2}{f_1})^2 + 1}}{2\frac{f_2}{f_1} + 1 - \sqrt{(2\frac{f_2}{f_1})^2 + 1}} \right)^{\frac{1}{2}} \frac{2\frac{f_2}{f_1} + 1 + \sqrt{(2\frac{f_2}{f_1})^2 + 1}}{\sqrt{(2\frac{f_2}{f_1})^2 + 1}} \right] \quad (5)$$

For many elements calculation of the attenuated spectrum yields:

$$S_n = 10 \log \left[\frac{\pi^2 \; e^2 \; (f_2/f_1)^{2n+1}}{4\left(2^{\frac{1}{2n}} \frac{f_2}{f_1} - 2^{\frac{-1}{2n}}\right)\left(\frac{1}{1 - \frac{1}{2n}} \frac{f_2}{f_1} - \frac{1}{1 + \frac{1}{2n}}\right)} \right] \quad (6)$$

f_2/f_1 as a function of τ/τ_{min} is calculated from the relationship:

$$\frac{f_2}{f_1} = 2\frac{\tau}{\tau_{min}} - 1 \quad (7)$$

derived from Fig. 3. Curves derived from the equations are illustrated in Figure 5.

Example. Suppose a diode switch is needed to protect a 1 GHz radar receiver from "transmit" signal leakage. The diode requires 10 volts to cause switching, and the transients must be below 200 microvolts to prevent receiver satuartion. The switching pulse is generated by a matched 50-ohm generator so that any of the pulse reflected by filters or the diode is absorbed back in the pulse generator. 94 dB of suppression is needed. Fig. 5 indicates that 100 dB of suppression may be obtained by using 5-element filters at a sacrifice of increasing the switching time by a factor of 5. Thus the switching speed becomes 6.2 nanoseconds. The filters for a series diode switch in strip line are shown in Figure 6. The low-pass and series capacitor filters are taken from Ref. 2, and the shorted quarter wavelength stub filter is taken from Ref. 3.

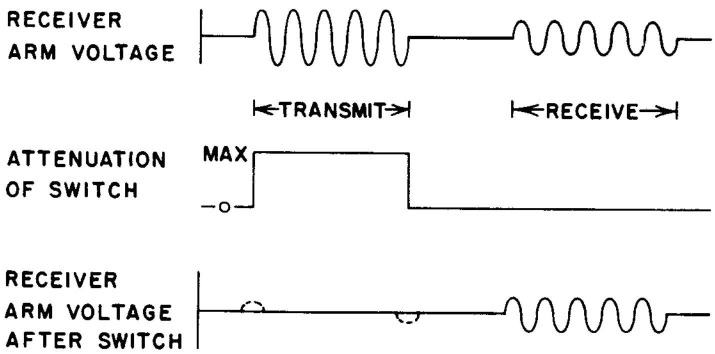

Figure 1. Receiver Arm Voltage and Switch Attenuation for a Diode-Switch-Protected Radar Receiver. (Dotted curves on lower trace represent undesirable switching transients in receiver arm.)

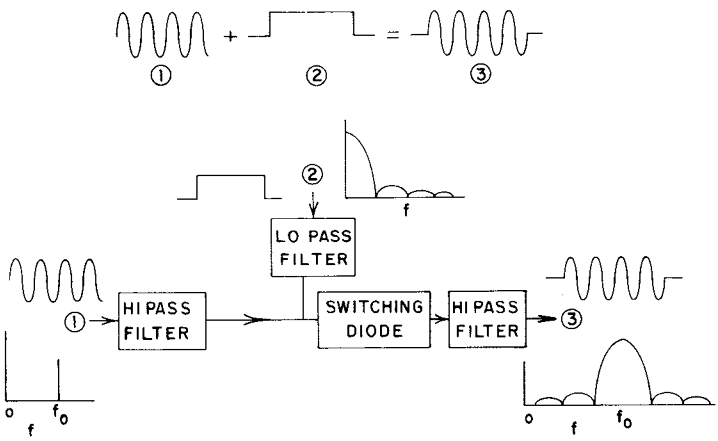

Figure 2. Filter Requirements of a Diode Switch

References.

1. R. V. Garver, "Theory of TEM Diode Switching", IRE Trans. MTT-9, pp 224-238, May 1961.
2. The Microwave Engineers" Handbook, pp 88-91, Horizon House, New York, 1965.
3. W. W. Mumford, "Tables of Stub Admittances for Maximally Flat Filters Using Shorted Quarter-Wave Stubs", IEEE Trans. MTT-13, pp 695-696, September 1965.

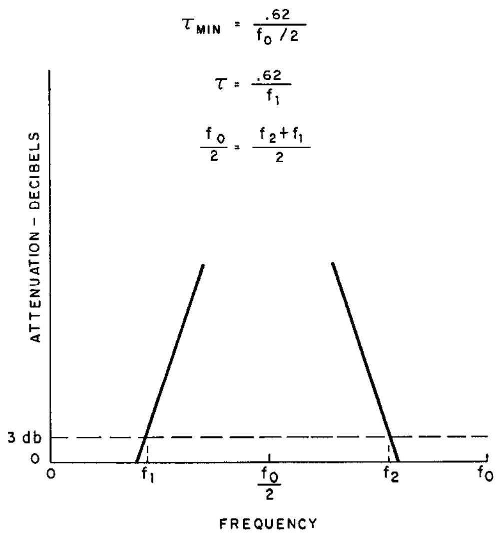

Figure 3. Attenuation of Overlapping Filters and their Resulting Switching Times.

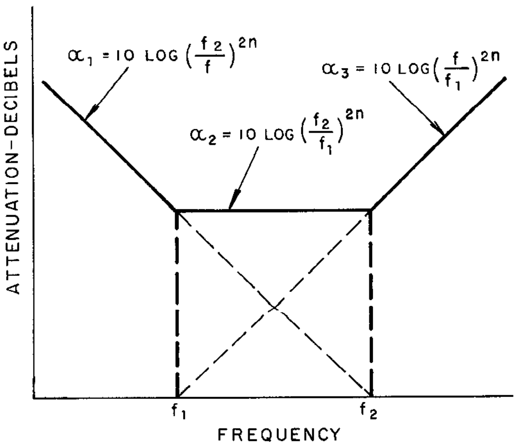

Figure 4. Attenuation of Low-Pass and High-Pass Filters in Series (by which modulation voltage is reduced to suppress transients).

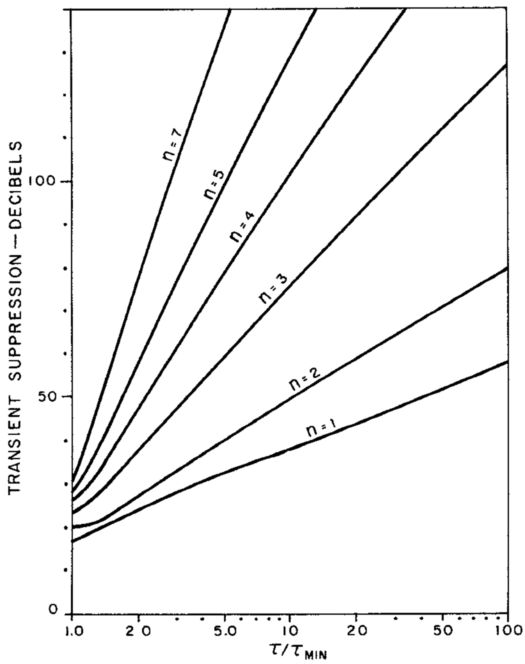

Figure 5. Transient Suppression as a Function of Number of Elements in Baseband Prototype Filter, and Increased Switching Time

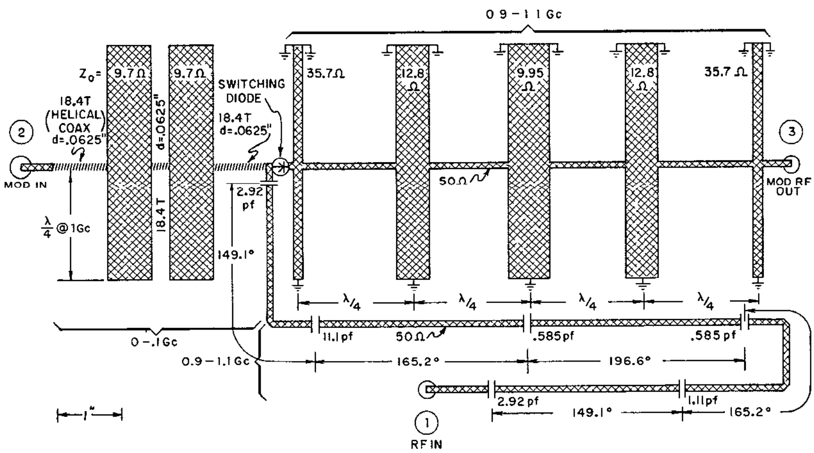

Figure 6. Strip Line Circuit for 1 GHz 6.2 nsec. Diode Switch with 100 dB Suppression.