VIII-2. SAMPLING FOR OSCILLOSCOPES AND OTHER RF SYSTEMS: DC THROUGH X-BAND

Wayne M. Grove

hp Associates, Palo Alto, California

Sampling techniques have long been used on periodic waveforms to achieve wide bandwidths in oscilloscopes and other applications.[1,2,3] The sampling oscilloscope, which is the electrical equivalent of the optical stroboscope, operates by sampling the voltage amplitude at progressively later points on successive cycles of a repetitive waveform. The state-of-the-art in sampling is the 4 GHz bandwidth presently available in sampling oscilloscopes. The purpose of this paper is to present the design requirements for extending this broadband sampling technique through X-band and then to describe one solution to the problem.

The bandwidth of a sampling device employing semiconductor diodes is determined entirely by the diodes, the sampling gate pulse and their electrical and mechanical interconnection to the rf transmission line being sampled. Therefore, this paper will be concerned with these basic elements combined in a single microwave component called a "sampling head".

Consider the general two-diode feedthrough sampling circuit shown in Figure 1. Signals being sampled (observed) need not be terminated at the sampler but can pass through without appreciable degradation. This allows high frequency measurements to be made without disturbing the system under test and is particularly useful in Time Domain Reflectometry. The purpose of the circuit is to periodically sample the voltage appearing on the transmission line. The bandwidth of the device is inversely proportional to the time for which the diode's impedance is low. The sensitivity of the sampler, analogous to conversion loss in a mixer, is determined by the efficiency of charge transfer from the input transmission line to the sampling capacitors.

The circuit of Figure 1 can be simplified by considering separatly the input sampling circuit and the diode gating circuit. Detailed calculations show that the R, L and C limitations of the input sampling circuit are more stringent than those set by the diode gating circuit. This can be seen from the sampling pulse shown in Figure 1 where the gate width at the bias level, t_g, can be considerably less than the risetime of the gating pulse.

Consider the input sampling equivalent circuit shown in Figure 2. Here, the effect of the line as a generator is represented by the impedance $Z_o/2$. Both diodes have been combined into one and the diode package capacity has been neglected, since it can be relocated and masked out. Writing the equation for the voltage, V_{d_s}, appearing across the diode junction as a result of an input voltage, and noting that $C \ll C_1$, yields the following:

$$V_{d_s} = \frac{e_{in}\left[\frac{1}{LC}\right]}{S^2 + S\left[\frac{R+Z_o/2}{L}\right] + \left[\frac{1}{LC}\right]} = \frac{e_{in}\,\omega_n^2}{S^2 + S\,2\delta\omega_n + \omega_n^2} \qquad (1)$$

where $\omega_n = \frac{1}{\sqrt{LC}}$, $\delta = \left[\frac{R+Z_o/2}{2}\right] \sqrt{\frac{C}{L}}$ and $L = L_1 + L_2$

The pole locations of Equation (1) determine the bandwidth and the step response of the sampling device. Assuming that a step response with less than 5% overshoot is desired, the damping factor δ should be approximately .7. Having set δ, there are many combinations of R, L and C which will yield bandwidths in excess of 12.4 GHz. For maximum sensitivity, the diode series resistance should be minimized. This means that the diode capacity should be as large as possible consistent with the minimum realizable L.

The calculations based upon the circuit of Figure 2 show that a bandwidth in excess of 12.4 GHz can be obtained with the following set of circuit parameters:

$$Z_o = 50\Omega$$

$$C \leq .2 \text{ pf}$$

$$L = L_1+L_2 \leq 250 \text{ ph}$$

$$R \leq 15\Omega$$

The interconnection of the sampling pulse and the diode gate is complicated by the requirement of a low inductance connection between the grounds of the input signal and the sampling capacitor. The two diode sampling configuration shown in Figure 3 yields the lowest inductance connection possible by making the grounds of the input signal and the sampling capacitor physically the same point. This is accomplished by splitting the ground of the coaxial transmission line to develop an impedance from one side of ground to the other. The sampling pulse can be introduced into the circuit at this point and will be coupled through the sampling capacitors to the diodes. At the same time, the sampling pulse will travel down the shorted transmission line, be inverted and travel back. This results in a differentiation of the sampling voltage step, resulting in a pulse.

The circuit just described can be implemented as shown in Figure 4. The input coaxial transmission line is stepped down in size and passed through a modified biconical cavity. The impedance of the line is maintained at 50Ω throughout the dielectric filled cavity. The electrical length of the cavity or the differentiation length is 50 picosec. The cones are truncated to provide room for the diodes and the sampling pulse entry to the cavity. The single sampling voltage step which drives the two cone faces couples through the sampling capacitors, turning the diodes on, and travels out towards the differentiating short. The voltage step is inverted and travels back towards the center of the cavity, turning the diodes off and proceeds out the sampling pulse coaxial line. The rf transmission line being sampled lies on a zero potential plane with respect to the sampling pulse providing approximately 40 db of isolation between the two lines.

The diode being used is a specially designed hot carrier diode housed in a unique three terminal package. The effect of the three terminal package is to relocate the package capacity so that it can be partially masked out by the use of dielectric in the cavity.

Some applications of sampling require that the VSWR of the sampler be held to a minimum at the expense of step response. This compensation can be accomplished by embedding the sampling diodes in a filter section designed for low VSWR.

Sampling heads of the type described in this paper have been assembled and tested. The typical experimental results for both the uncompensated and compensated samplers are shown in Figure 5. The bandwidth and VSWR data obtained on both types of samplers showed good agreement with the predicted curves. The typical bandwidth obtained is 3 to 4 times that commercially available.

[1]R. Sugarman; Rev. Sci. Instr. 28, 933 (1957).
[2]R. Carlson; Hewlett-Packard Journal 11, 5-7 (1960).
[3]W. Grove; Hewlett-Packard Journal 15, 11 (1964)

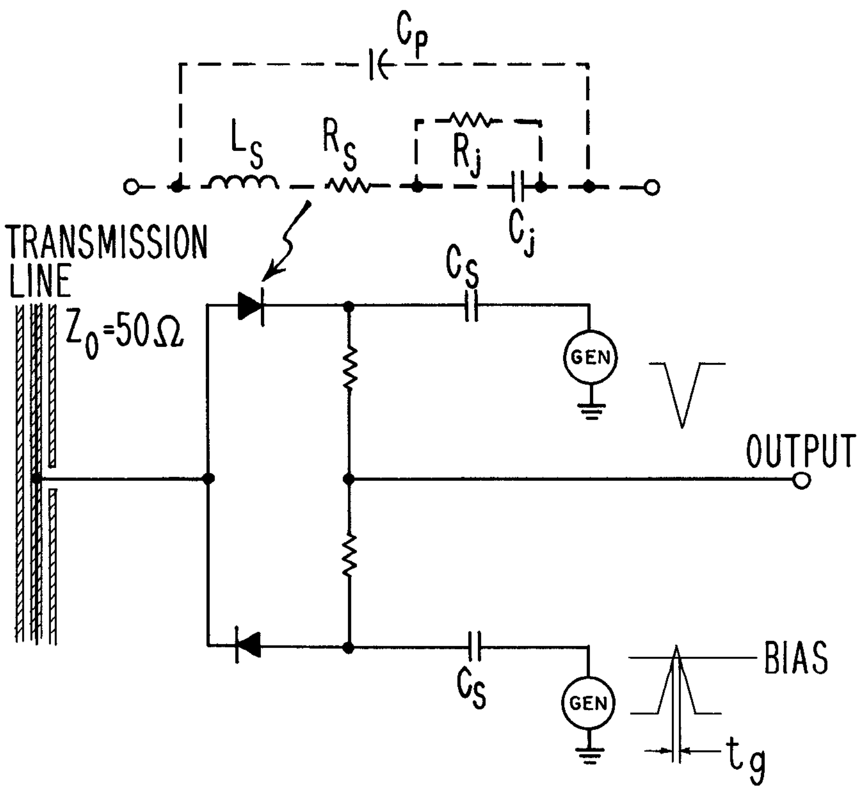

Figure 1. General Two-Diode Sampling Circuit.

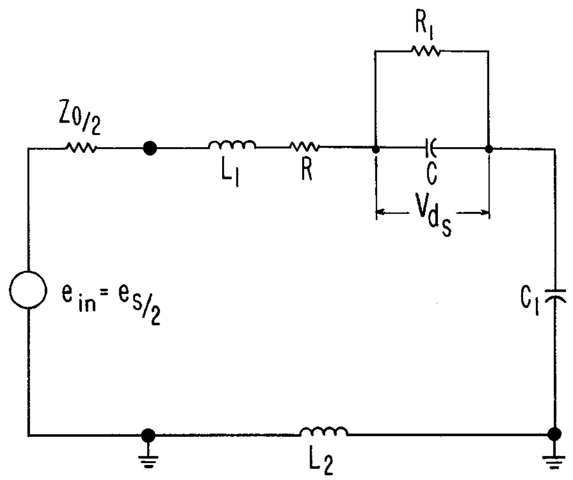

Figure 2. Input Sampling Equivalent Circuit.

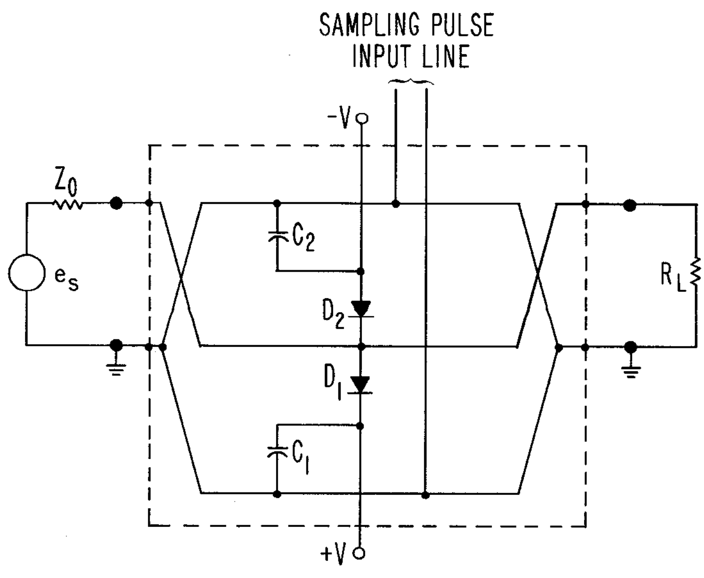

Figure 3. Two-Diode Sampling Circuit.

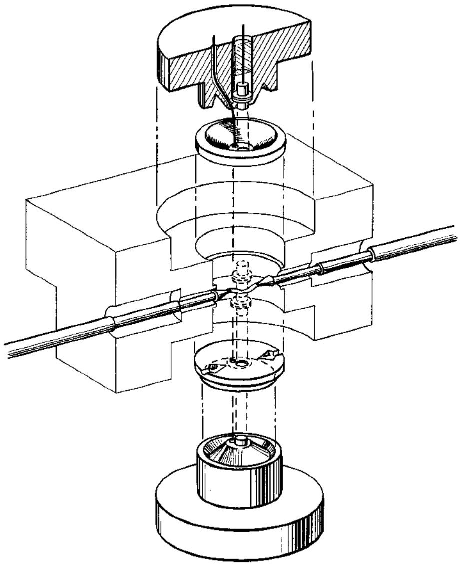

Figure 4. Biconical Sampling Cavity.

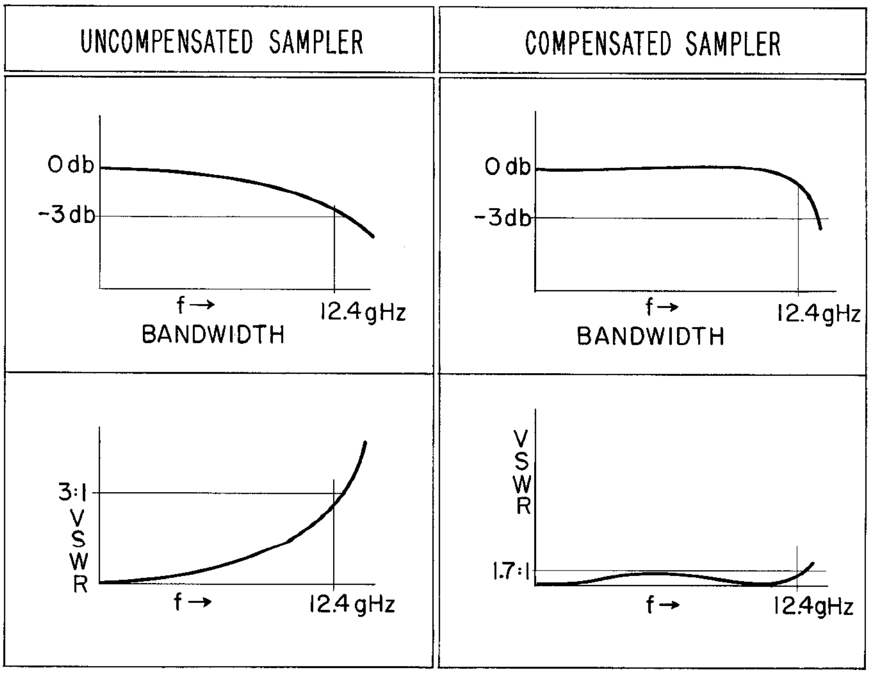

Figure 5. Typical Measured Performance.

TRW SYSTEMS

One Space Park, Redondo Beach, California

TRW Systems is an operating group of TRW Inc., a diversified manufacturer of aerospace, electronic, and automotive systems and components