8.1: BANDWIDTH OF TEM DIODE LIMITERS

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To date diode limiters are either parametric frequency converting devices [1-6] or simply diodes shunting a transmission line [7-12]. The parametric limiters are narrow band because they must be made using cavities. Future techniques might improve their bandwidth but it is felt that in the limit their bandwidth would approach that of the techniques discussed here. The derivation of the bandwidth of a limiter consisting of diodes shunting a TEM transmission line is similar to the derivation of the bandwidth of a series diode switch[13]. The attenuation α of an admittance G + jB shunting a transmission line of characteristic admittanc Y_o is given by the equation

$$\alpha = 10 \log \left[\left(\frac{G}{2Y_o} + 1 \right)^2 + \left(\frac{B}{2Y_o} \right)^2 \right].$$

The attenuation for various inductances, capacitances, and resistances shunting a 50 ohm transmission line is plotted versus frequency in Figure 1.

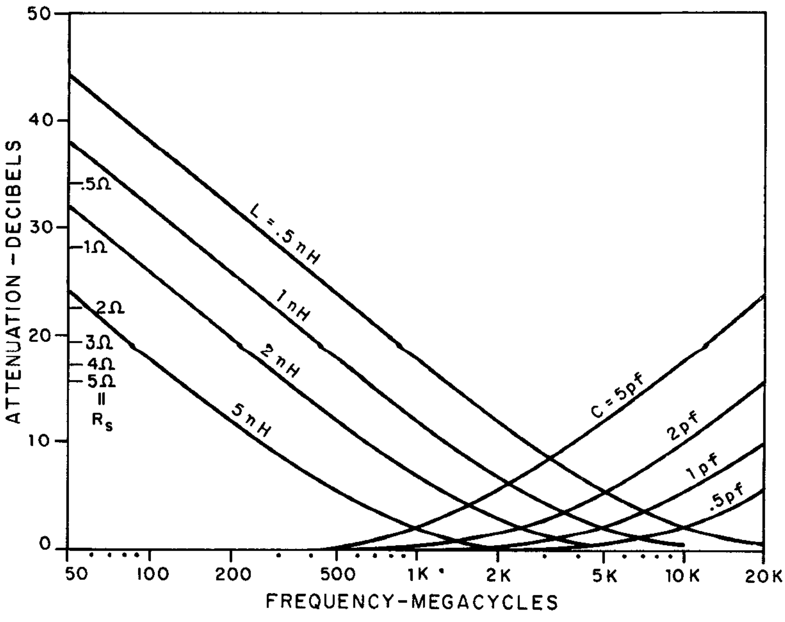

Fig. 1. Attenuation-bandwidth of a diode shunting a 50 ohm transmission line as a function of diode inductance and capacitance. The limit on maximum attenuation imposed by spreading resistance is given along the ordinate.

The capacitive curves in Figure 1, representing the sum of the mount capacitance C_m and zero bias diode capacitance C_o, portray the insertion loss bandwidth of a limiter using shunt diodes. The diode spreading resistance R_s limits the maximum isolation possible with a shunt diode limiter, while the diode "whisker" inductance L_w limits the isolation bandwidth as portrayed by the inductance curves in Figure 1. If an untuned diode is mounted shunting the TEM transmission line, the isolation and insertion loss will be just as shown in Figure 1. In most applications, however, best results are obtained by tuning the limiter to the design frequency. The maximum isolation is tuned by putting a capacitor in series with the diode and fabricating a very small inductor shunting the diode to complete the d.c. path. The capacitor series-resonates with L_w, while the inductor parallel-resonates with $C_o + C_M$ at the design frequency. From Figure 1 it can be seen that a "pill" varactor with $L_w = 0.7$ nh will provide greater than 20 db isolation over a 600 Mc/s bandwidth. Shunt diode limiters made with varactor diodes can be made to withstand up to 100 watts average incident power and up to 2000 watt-microsecond pulse energy. These limiters are reflective and can be made only for frequencies below the diode self-resonance at which the equivalent circuits mentioned above are valid. In a 50 ohm transmission line, the power output is limited to about 2 mw for germanium, 10 mw for silicon, and 20 mw for gallium arsenide, being a function of the voltage at which the various diodes begin forward conduction.

A matched limiter can be made in a TEM transmission line using the technique developed at X band[14]. When series diodes and matched loads are combined with a 3 db coupler as shown in Figure 2, limiting action results. Assuming the 3 db coupler to be perfect, the attenuation of the device is determined by the reflections from the diode-matched load combination. Two identical diodes of admittance G + jB in TEM transmission line of characteristic admittance Y_o, used with a 3 db coupler, will give attenuation α according to the relationship

$$\alpha = 10 \log \left[\left(2 \frac{G}{Y_o} + 1 \right)^2 + \left(2 \frac{B}{Y_o} \right)^2 \right].$$

The attenuation as a function of diode parameters and frequency is given in Figure 3 for diodes mounted in a 50 ohm transmission line. Again the curves portray the bandwidth if the diodes are tuned. Two MA4254 ($C_o \approx 1$ pf) pill varactors were tuned to 1100 Mc/s and mounted in MX24 stripline series "pill" varactor mounts. The diode mounting capacitance C_M of 1 pf adds to C_o to give $C_o + C_M = 2$ pf. The insertion loss for incident power less than 1 mw is less than 1 db from 900 to 1300 Mc/s, the bandwidth of which agrees with Figure 3. The isolation for incident power greater than 5 watts is 25 db which agrees with Figure 3 (L_w being 0.7 nh). The VSWR of the limiter is less than 1.2 for all incident power levels. The burnout power is calculated to be 20 watts average and 150 watt-microseconds incident pulse energy.

Above 3 Gc/s it becomes increasingly difficult to make limiters

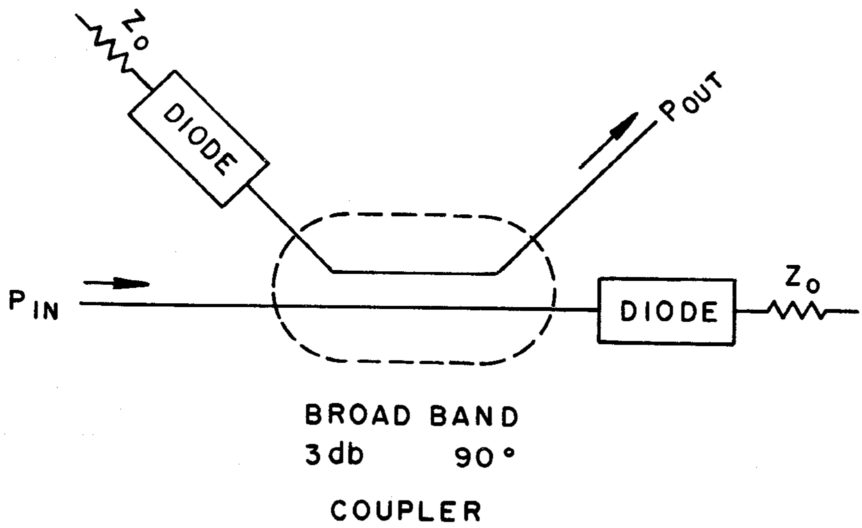

Fig. 2. Schematic diagram of a matched limiter using two diodes with a 3 db coupler.

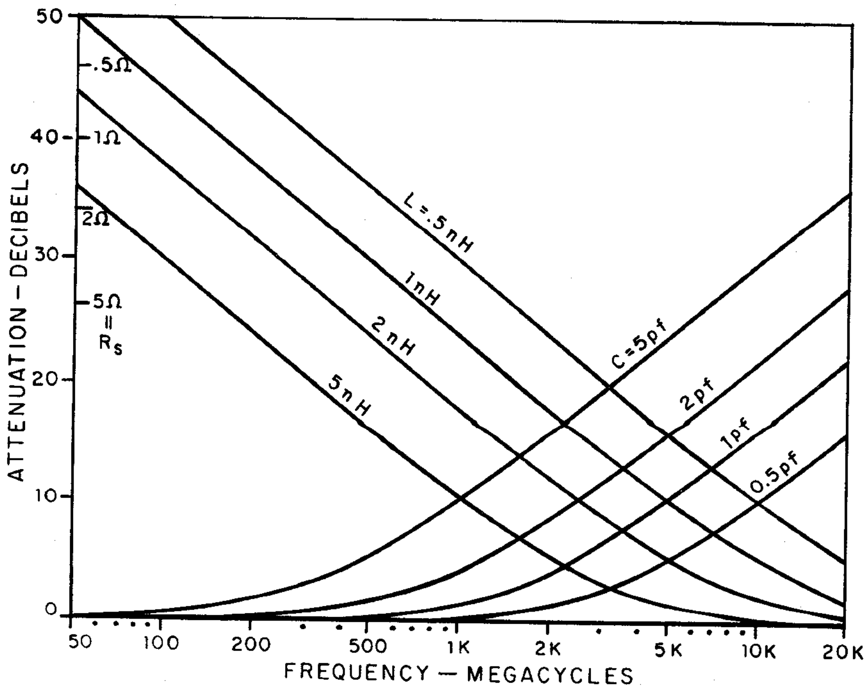

Fig. 3. Attenuation-bandwidth for diodes used with a 3 db coupler as a function of diode inductance and capacitance. The maximum attenuation as a function of spreading resistance is given along the ordinate.

using series diodes with a 3 db coupler. At higher frequencies, the "whisker" inductance L_W of the diode resonates with the depletion layer capacitance C_D or the diode cartridge capacitance C_c and obscures the variation in C_D with power, this being the basis for limiting. It is necessary at higher frequencies to make use of the diode self-resonance by controlling it. As seen in Figure 4, a diode will limit if L_W

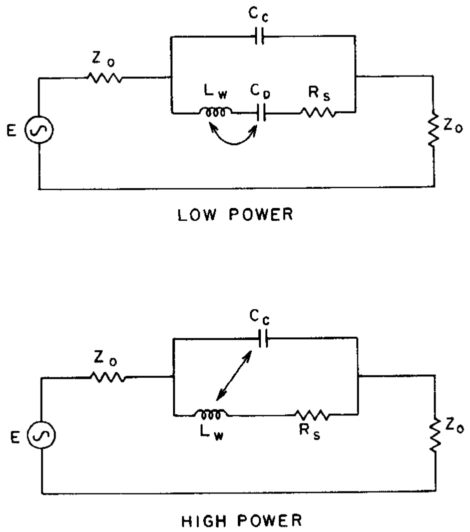

Fig 4. Equivalent circuits of a resonant diode in series in a transmission line. At low power, the series resonance between L_w and C_D causes the diode to have a low impedance, thus having a low attenuation. At high power, C_D is shunted by conduction current, allowing L_w to parallel-resonate with C_c. The resulting high impedance of the diode causes high attenuation.

series-resonates with C_D at low power levels, and parallel-resonates with C_c at high power levels. The bandwidth of the isolation and insertion loss of this limiter will be dependent on the ratio of the reactance of the whisker inductance X_{Res} at the resonant frequency to the characteristic impedance Z_o of the transmission line in which the diode is mounted. The relationship between isolation, insertion loss, bandwidth and X_{Res} is shown in Figure 5.

The maximum isolation and minimum insertion loss will occur at the resonant frequency f, and will be limited by the diode cutoff frequency at zero bias f_c, and X_{Res} as portrayed in Figure 6.

To illustrate, suppose a limiter is needed at 3 Gc/s with 20 db isolation, less than 1 db insertion loss, and 10 per cent bandwidth. From Figure 5, 20 db isolation and 10 per cent bandwidth give .05 db insertion loss for $X_{Res} = 2Z_o$. If we use a varactor diode with L_W = 2 nh, then Z_o must be 18 ohms, while C_D at zero bias and C_M each have to be 1.5 pf. From Figure 6, 20 db isolation and $X_{Res} = 2Z_o$ gives $f/f_c = 0.1$

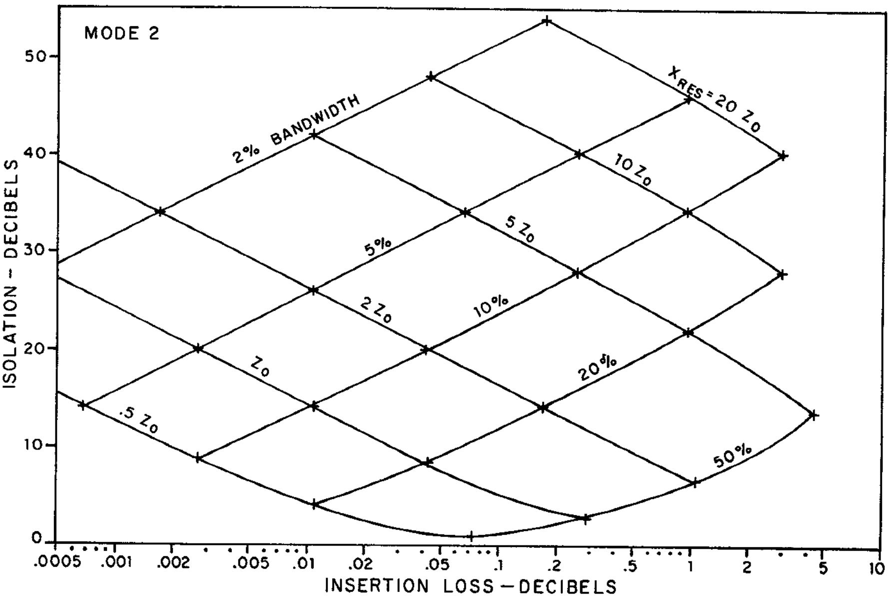

Fig. 5. Minimum isolation and maximum insertion loss of a limiter using a resonant diode in series with the center conductor as a function of bandwidth and $X_{R_{es}}$ (reactance of L_s at resonance). These curves also describe the characteristics of a limiter making use of resonant diodes in shunt with a 3 db coupler with Z_o replaced by $\frac{Z_o}{4}$.

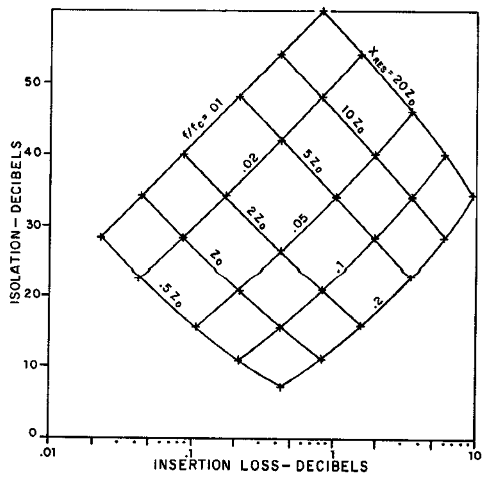

Fig. 6 Maximum isolation and minimum insertion loss of a limiter using a resonant diode in series with the center conductor as a function of $X_{R_{es}}$, center frequency f, and zero bias diode cutoff frequency $f_c = (2\pi R_s C_D)^{-1}$. These curves also describe the characteristics of a limiter making use of resonant diodes in shunt with a 3 db coupler when Z_o is replaced by $\frac{Z_o}{4}$

for an insertion loss less than 1 db. Then the cutoff frequency of the diode at zero bias must be 30 Gc/s or about 75 Gc/s at maximum reverse bias.

The limiters described in this paper should exhibit no spike leakage since limiting is caused by diode conduction which for varactors typically begins in less than half of a microwave cycle. The dead time of the limiters will be the same as the recovery time of the varactors, which is typically less than ten nanoseconds.

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