# AN ULTRA LOW TRANSIENT GaAs FET VHF SWITCH

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ABSTRACT

A simple unbalanced GaAs FET switch is described which has 20 dB lower peak transients than commercial balanced diode designs. An auto-transformer neutralization circuit provides more than 55 dB off-isolation over a three octave bandwidth. A novel scheme which derives both drive and bias from Schottky TTL gates eliminates the bipolar supplies and discrete drive circuitry usually found in high speed switches. A low level transient caused by carrier trapping in the GaAs material is described.

## LOW TRANSIENT SWITCHING AT VHF

A single-pole multi-throw switch can be used in some communications systems to feed one of several different IF signals to a single detector. Considerable hardware can be saved if most of the IF gain can be placed on the single detector path rather than the many IF paths. However, this requires very low transient switching, which is difficult to achieve at high switching speeds.

At VHF, the coupling components used in diode switches can couple considerable drive energy into the RF path. Much of this can be cancelled by using a balanced configuration, but slight imbalances can still result in large transients.

In an FET switch, the drive signal couples into the RF path through the gate to channel capacitance. By using microwave GaAs FETs, this capacitance is less than a few tenths of a picofarad, and the transient coupling into the RF path is very small, even in an unbalanced configuration. GaAs FETs can also switch in under a few nanoseconds, with very little drive power.

The coupling between the drive signal is a high-pass structure, and much of the transient comes from the fast drive edges. Transient performance can improve considerably (at some cost in speed) by slowing these edges with a low-pass filter in the drive line. Because of the high input impedance of the FET, a simple RC filter works quite well. The time constant can be easily adjusted for the best trade-off between transient performance and speed for any particular system.

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The schematic in Figure 1 shows the basic switch. The capacitance from gate to drain is typically smaller than from gate to source, so the drain is connected to the output to further minimize transients. The FET source requires a dc return, either through the RF input as shown, or with a bias choke, although the reactance of the choke can degrade the transient performance.

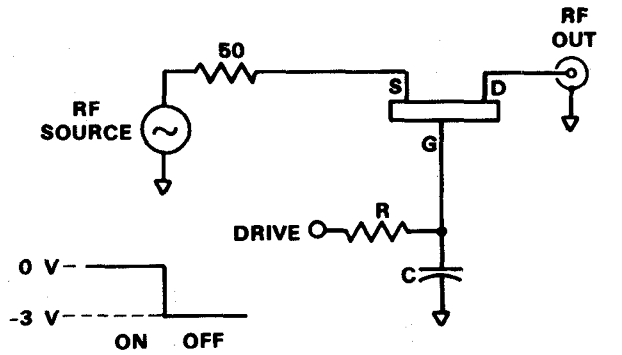


Figure 1. Basic FET switch with drive filter.

Figure 2 shows the drive feedthrough transients of a commercial "transient-free" balanced diode switch, and of a single unbalanced GaAs FET switch. Note that the voltage scale of the diode switch transient is twice that of the FET switch. The difference in peak amplitude is over 20 dB.

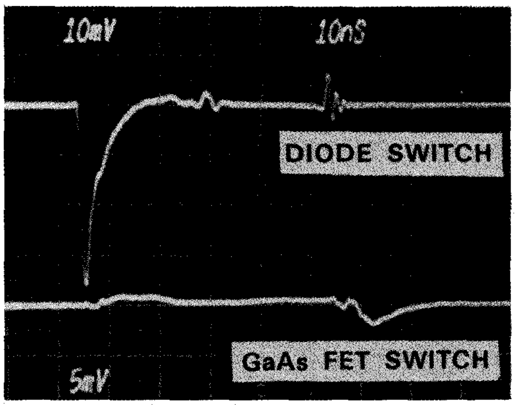


Figure 2. Drive feedthrough transient of a balanced diode switch and a GaAs FET switch.



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ISOLATION CONSIDERATIONS

Because of their fast switching capability, GaAs FETs are finding increasing use as microwave switches in both single gate and mutiple gate configurations(1-4). One of the problems with GaAs FET switches is their poor off isolation. At microwave frequencies, isolation of 20 to 30 dB has been obtained in a single switch by resonating the feedthrough capacitance with a parallel inductor (5). However this technique only works well for bandwidths of 10% or less.

At VHF, the isolation of a simple GaAs FET switch is typically between 25 and 35 dB. This is adequate for some applications, but in a wide dynamic range IF system, isolation of 50 dB or more may be required, and over broader bandwidths than can be achieved with parallel inductor neutralization.

The schematic in Figure 3 shows how an auto-transformer can be used to neutralize the feedthrough capacitance of the GaAs FET. The upper end of the transformer is 180 degrees out of phase with the input signal, and is coupled to the output by the trimmer capacitor. To first order, when the trimmer is adjusted to the same value as the feedthrough capacitance of the FET, the two signals will cancel at the output. The frequency range of this technique is limited only by the parasitic mismatches in the two signal paths, and the bandwidth of the transformer.

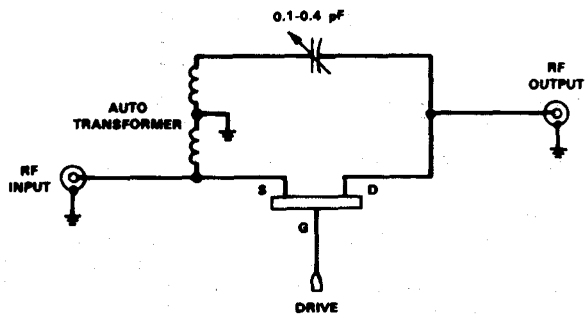


Figure 3. Basic FET switch with auto-transformer neutralization.

The network analyzer photograph in Figure 4 shows the performance of this technique. The top trace shows the "ON" insertion loss of 1.5 dB. The center trace shows the isolation of an un-neutralized switch, and the bottom trace shows the neutralized performance. There is a 20 dB improvement in off-isolation from below 50 MHz to almost 250 MHz, and the absolute isolation is better than 55 dB from 25 MHz to 200 MHz.

DRIVE CIRCUITRY

One problem common to both diode and FET switches is the drive circuitry, which typically requires bipolar supplies, and high speed discrete level shifting. With FETs, the bipolar supplies can be eliminated by biasing the channel with a positive voltage, but this can still require discrete gate drive for fast switching.

The output swing of Schottky TTL is about 3.4 volts, which is perfect for switching most GaAs FETs. To turn the FET on, the channel must be

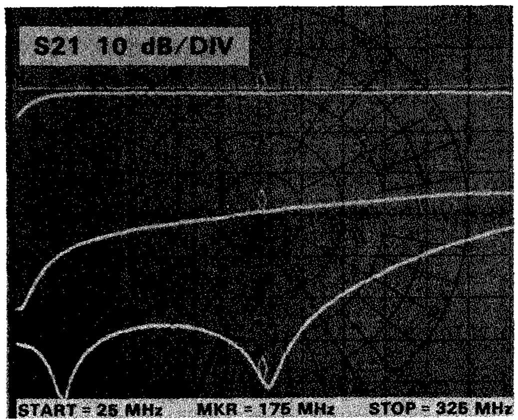


Figure 4. Insertion loss, and isolation of un-neutralized and neutralized switch.

biased with a voltage equal to the high output of the drive gate. Measurements of different lots of Schottky gates has shown that the maximum difference between the high outputs of any two gates within a single package is typically less than 5 mV when equally loaded. The maximum deviation one should encounter is less than 20 mV, which is still small enough to give proper switching. Because the gates are virtually identical, and in the same package, they will track over temperature as well. By driving and biasing the FET from the same IC package, the FET can be switched at high speeds with a single power supply and a minimum number of discrete components.

THE COMPLETE CIRCUIT

The circuit in Figure 5 shows how the bias, drive, and neutralization are combined in the final design. Because the transformer must have a high enough impedance not to load the input line, it also makes an excellent bias choke. The two gates are loaded with 10K ohms, and the gate drive RC filter has a 2.5 nanosecond time constant. This results in a switching speed of roughly 20 nanoseconds. Only a single switch is shown, but several switches can be connected together directly if they are all biased from the same IC.

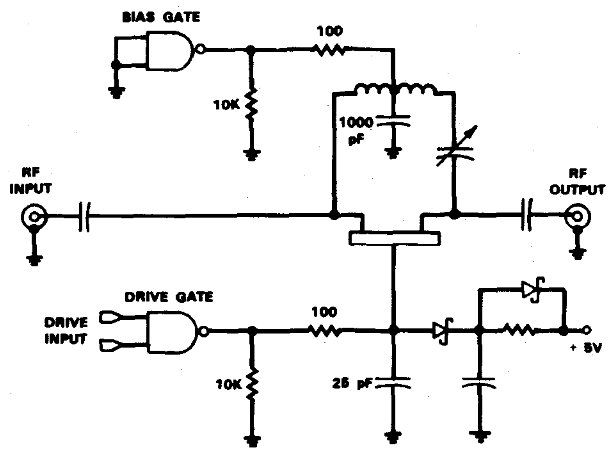


Figure 5. Complete switch with bias and drive.

The clamping network prevents the FET gate junction from being forward biased during power-up. This is only necessary if the switch can come up in the "ON' state, and the time constant of the bias filter is longer that that of the drive filter.

## COMPONENT CONSIDERATIONS

Most small-signal microwave GaAs FETs will work well as a low transient switch, the two critical parameters being the pinch-off voltage, $V_p$, and the saturation current, Idss. Unfortunately, these are usually specified very loosely for GaAs FETs, and repeatable switch performance may require special screening or specification of the devices. A low "ON' resistance will minimize insertion loss, and is roughly given by Ron = $V_p/(2xIdss)$. Typical FETs range from 10 to 20 ohms.

The pinch-off voltage is important because most of the switching action takes place when the gate is near $V_p$. If a drive low-pass filter is used to reduce transients, $V_p$ must be specified close to the center of the drive swing, or asymetrical switching delays will occur. Figure 6 shows the timing waveforms for a GaAs FET with a pinch-off voltage equal to three-fourths of the drive level, and the resulting asymetry in switching times.

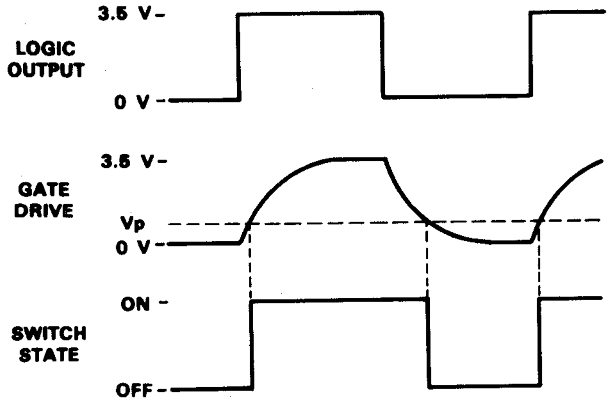


Figure 6. Timing asymetry caused by drive filter and low pinch-off voltage.

Another problem which GaAs FETs can exhibit is a low level turn-on transient caused by carriers trapped by imperfections in the lattice, which are then released slowly over time. This produces an undershoot in the insertion loss which can last for several seconds. Fortunately, the magnitude of the transient is typically less than 0.1 dB, and it should not be a problem in most systems. Although of little use to the designer, the transient is reduced if excess carriers are injected into the material by opening and illuminating the device. Figure 7 shows the network analyzer traces of the switching transient of a GaAs FET switch with and without illumination. Bacause this is a process related problem, device screening may be required if this effect is significant.

The auto-transformer should be designed to be self-resonant at band center, to maximize its impedance and minimize transients from reactive loading of the input. A small core and fine bifilar wire will give the highest impedance at

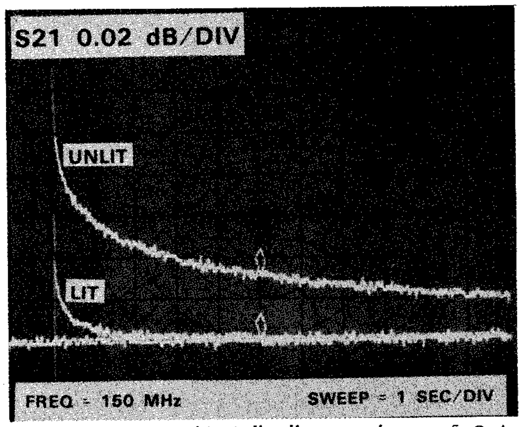


Figure 7. Detailed "ON" transient of GaAs FET switch with and without illumination.

self-resonance. The transformers used in these circuits were wound on a 3 mm diameter toroid of "SF" powdered iron material.

Because of its low value, the trimmer capacitor can be difficult to obtain commercially. Good results have been obtained by building a parallel strip capacitor into the top two layers of a multilayer PC board, and trimming the top strip (very carefully) with a knife.

## CONCLUSION

Although the principle advantage of this switch is its superior transient performance, it also has low insertion loss and high isolation over wide bandwidths at VHF. The drive system shown provides fast switching with a single supply and a minimum of components, but other drive schemes can be used to obtain even faster speeds, or low power consumption. This design can be used as a building block in many multiple switch configurations for even higher isolation or lower transients.

## ACKNOWLEDGEMENTS

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