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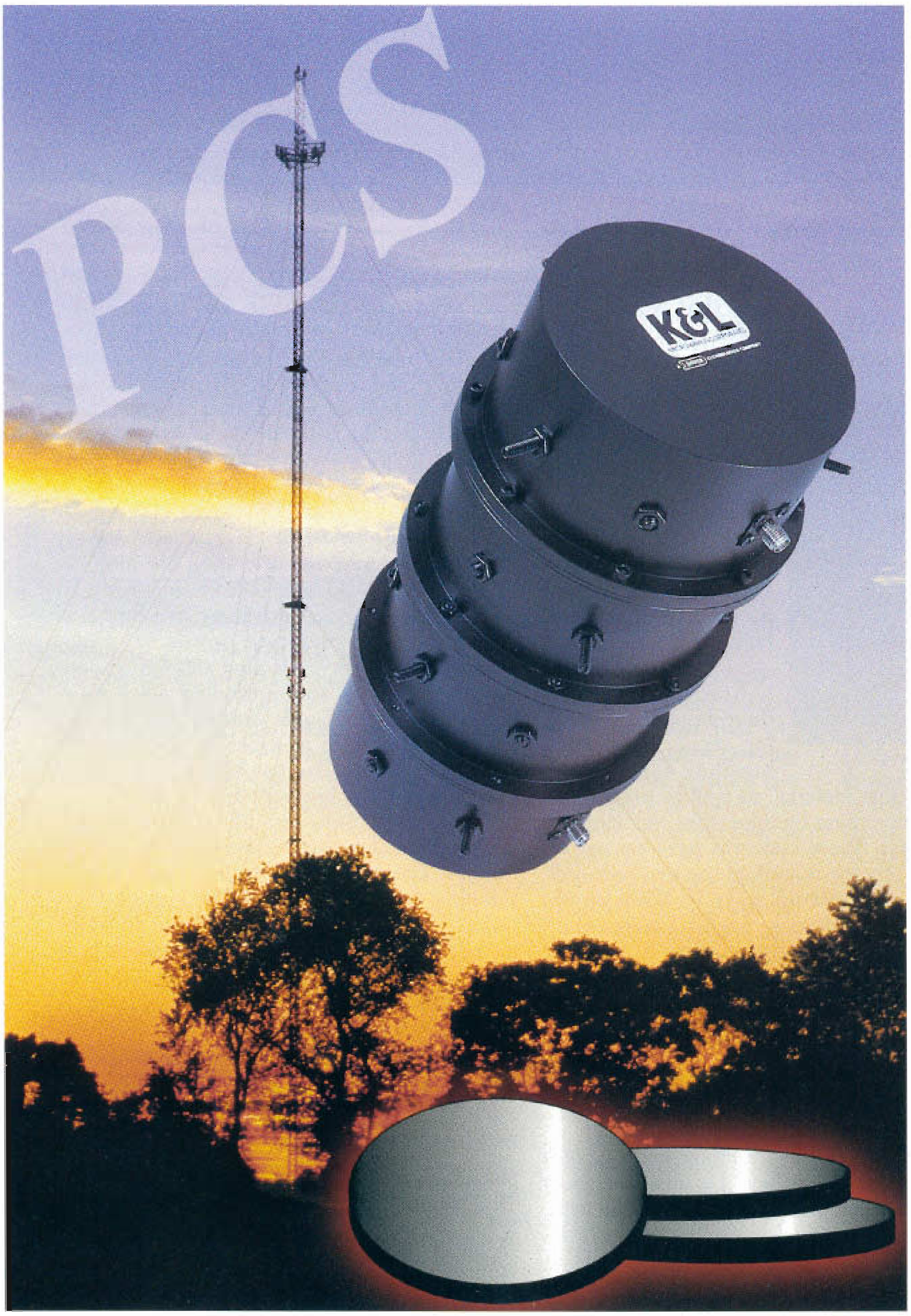

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Receiver Protectors: A Technology Update

The 1970s witnessed the advent of modern radar systems employing transmitters that operate at wide pulse widths and high duty cycles, which caused a major shift in receiver protector development. New techniques were conceived to allow the development of fast recovery time receiver protectors that would cope successfully with the new radars' wide pulse and high duty cycle characteristics. For the most part, these new techniques focused on reducing recovery time, developing true first-pulse firing pre-transmit/receive (T/R) tubes and increasing the power-handling capability of diode switches and limiters.

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Since that time, there has been increasing concern about the handling and disposal of radioactive material, as well as pressure to increase operating lifetime (thus reducing life cycle costs). These concerns have caused receiver protector manufacturers to redouble their efforts to find ways to allow diode switches and limiters to handle a larger share of the receiver protector burden. This article discusses state-of-the-art techniques that are being employed currently to meet the requirements of modern radar systems while simultaneously reducing tube radioactive content and increasing life.

BACKGROUND

In general, the receiver protector is not a single component. Rather, it is an assembly of components, each based on a different technology and individual operating characteristics. These components can be thought of as building blocks. The successful receiver protector design incorporates the combination of building blocks that provides the best performance for the lowest cost, taking into consideration the requirements of the application and the various trade-offs involved in employing a particular technology.

The basic receiver protector building blocks are pre-T/R tubes, T/R tubes, ferrite limiters, diode limiters and multipactors. The pre-T/R tube has the highest power-handling capability and a quick recovery time. The T/R tube has medium power-handling capability and provides the best value in terms of protection capability vs. cost. Both the pre-T/R and T/R tubes contain radioactive primer and have limited operating life. The ferrite limiter offers moderate power handling, a fast recovery time and no inherent operating life limit. In addition, it is relatively expensive and has relatively high insertion loss. The diode limiter is versatile with moderate power handling. Diode use allows controlled short-time-constant attenuation and equivalent noise resistance functions. Diode limiters provide fast recovery time with no inherent operating life limit. The multipactor has high average power handling and fast recovery time (< 10 ns).

The diode limiter is the only completely self-contained passive receiver protector technology. The other technologies listed are prelimiting devices that exhibit RF leakage characteristics too high for receivers to withstand. One or more diode limiter stage is used behind these devices to achieve low RF leakage levels.

The exact recovery time and power-handling ability of any receiver protector will depend upon the unique environment (duty cycle and operating temperature) in which it

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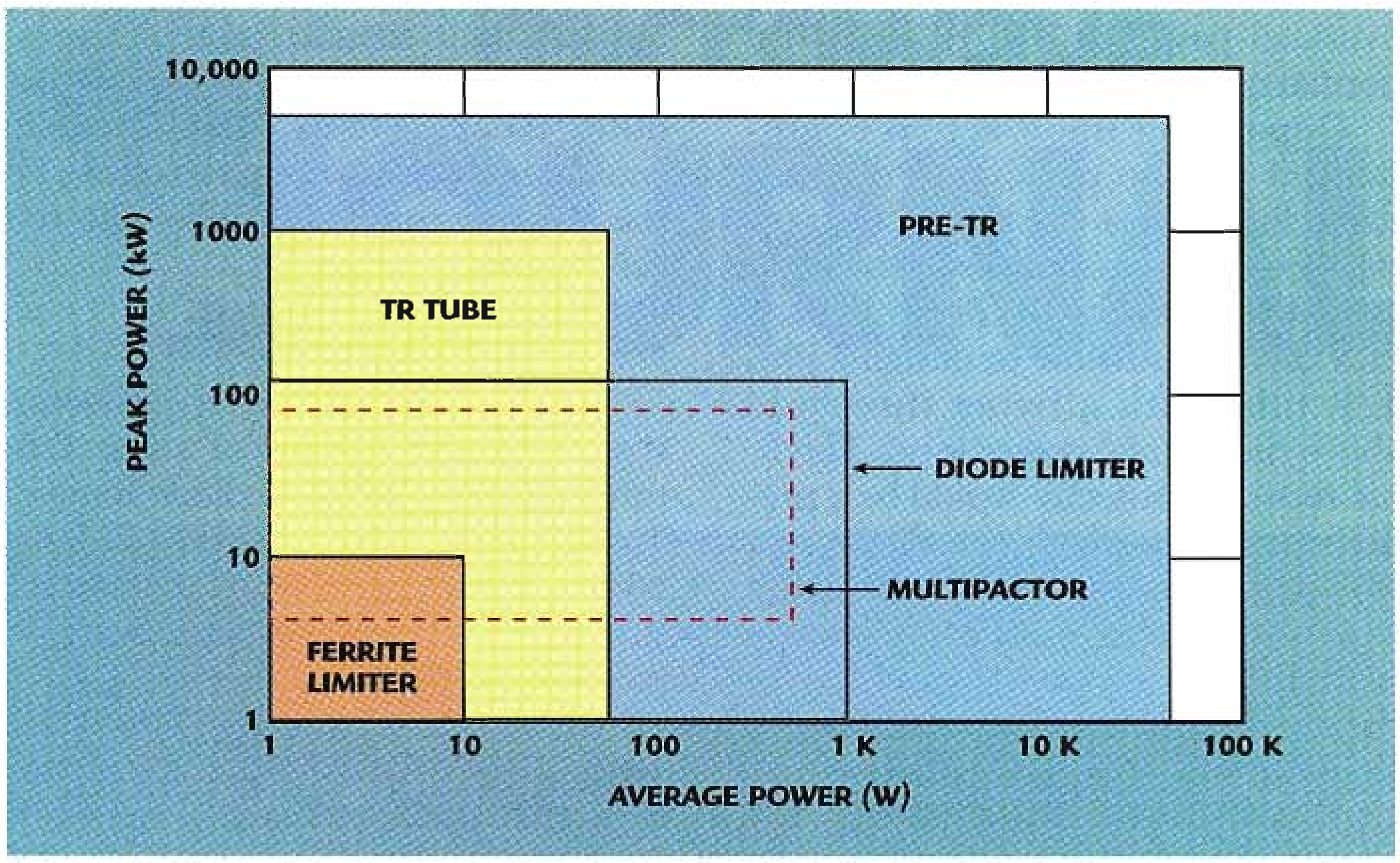
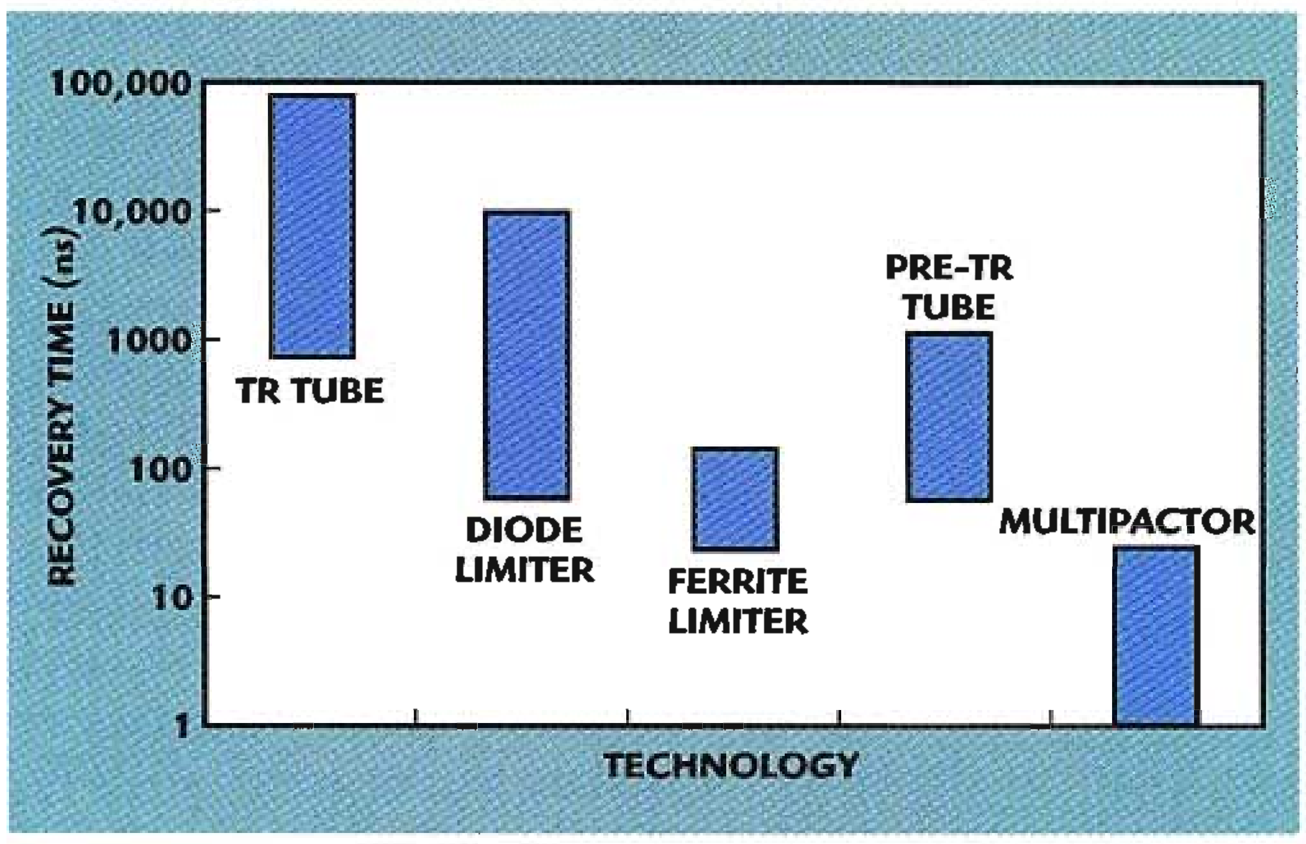


▲ *Fig. 1 Typical receiver protector operating range.*

▼ *Fig. 2 Typical recovery time.*



must operate. ***Figures 1*** and ***2*** show typical operating ranges for each of the building blocks.

The remainder of this article focuses on cutting-edge techniques in the receiver protector technology. These techniques are employed to achieve fast recovery time (10s of nanoseconds), extended operating life, reduced radioactive material content or all of these characteristics.

AN ALL-SOLID-STATE APPROACH

The passive all-solid-state diode limiter is normally the desired solution for most receiver protector applications. The benefits of the all-solid-state approach are numerous and include unlimited operating life, passive operation, fast recovery time, no radioactive priming and versatility (which means the limiter can perform multifunction roles).

The main factor that confines the use of passive diode limiters is power-handling ability. Although great advances have been made, most applications involve power and duty cycle characteristics that exceed today's diode limiter capability. The limiter diode's handling capability is primarily a function of peak power and pulse width. The choice of diodes will greatly affect the limiter's power-handling ability. However, trade-offs exist. Diodes that handle relatively more power will exhibit longer recovery times. Also, they will tend to have higher leakage powers. These drawbacks could require the use of additional stages of lower level limiters with the resulting increase in insertion loss and cost.

One way to enhance the power-handling capability of an all-solid-state unit is to actively bias the diodes during the high power pulse. Thus, instead of a passive limiter, the receiver protector would be an SPST switch. Actively biased diodes will handle a great deal more power than when they operate passively. The primary reason for this increase in power handling is that, when operated passively, a limiter diode will absorb more energy per pulse than when switched actively. In the passive mode, the limiter diode reacts to the onset of the transmitter pulse, self conducts and drives itself from its high impedance state to its low impedance state. This transition occurs during the leading edge of the transmitter pulse. As the diode transitions from high to low impedance, it travels through a point at which it is well matched to the transmission line. Thus, for a short period of time, the diode absorbs a relatively high percentage of the leading edge of the transmitter pulse. Once the diode is in full conduction, the percentage of absorbed power is very low. The absorbed energy causes a thermal rise in the diode junction, which ultimately causes the diode to fail. To operate reliably, junction temperatures must be kept below 175°C.

When operated as a switch, the diode should be driven into the low impedance state prior to the onset of the transmitter pulse. In this way, the diode already will be fully biased into its low absorption state before it is subjected to the high power pulse, resulting in a lower amount of absorbed energy per pulse.

A secondary factor is that, when actively biased, it is possible to drive a diode much harder into conduction than is possible in a practical passive circuit. Driving a diode harder into conduction will also result in less energy absorbed per pulse.

The disadvantage to the biased diode switch approach is that, being active, it requires a driver and a control signal that is synchronous with the transmitter pulse. Thus, the possibility exists that a failure in the control signal during transmission could cause the switch (and, possibly, the receiver) to be destroyed unless additional fault-indication circuitry is also employed in the system. In any case, a switch offers no protection against asynchronous signals or signals that may be incident upon the radar from external sources.

If the asynchronous signals were expected to be of a low level, one possible solution is a combination switch/limiter. The active switch would be the first stage and would protect against the synchronous transmitter pulse. This stage would be followed by a passive diode limiter that would provide cleanup limiting during normal system operation as well as a measure of protection against external signals.

PRE-T/R LIMITERS

When the required power handling exceeds a diode limiter's capability and fast recovery time is needed, one possible solution is to place a pre-T/R tube in front of the limiter. The pre-T/R tube serves as a prelimiting device whose function is to cut the power to a level that can be handled by the diode limiter. The pre-T/R tube will add less than 0.2 dB to the assembly's insertion loss characteristics. In return, it will increase power handling by orders of magnitude while maintaining very fast recovery time performance.

The pre-T/R units are gas tubes that have limited operating lifetimes. The tubes' lifetime is affected by the operating power and duty cycle conditions, as well as the volume of gas used. Typically, the end-of-life failure mode requires long recovery time caused by gas cleanup. Gas cleanup is a slow process that takes place over the life of the pre-T/R tube. Thus, a graceful degradation in performance is observed up to, and after, the end of life has been reached. Catastrophic failure does not occur normally in a device of this type.

For pre-T/R tubes, a reasonable rule of thumb for lifetime is approximately 2000 operating hours. For an additional cost, longer life may be possible in some cases through the use of enlarged gas reservoirs and/or multiple-bulb designs.

A QUASI-SOLID-STATE DESIGN APPROACH

Power handling in most receiver protector applications is specified in two components. Normal operating power is the maximum power that will be incident upon the receiver protector when the system is operating normally. Overload power is the power incident upon the receiver protector in the event of a system fault, which causes a high reflection into the receiver channel. Typically, overload power is 7 to 10 dB above normal operating power.

Depending upon actual conditions, it may be possible to design a diode limiter that can handle the normal power successfully even though it cannot tolerate the overload. If so, it may then be possible to design a pre-T/R tube with a firing threshold above the normal power level. The final receiver protector would be a pre-T/R limiter in which the diode section performs the main protection function during normal operation (while the pre-T/R sits quietly). In the event of an overload, the pre-T/R fires to protect the diode limiter.

This quasi-solid-state design approach has all of the benefits of the pre-T/R limiter discussed previously. But, because the pre-T/R does not fire under normal operating conditions, this approach has a much longer useful operating life.

In cases where the normal operating power is too much for a passive limiter, it may be possible to employ an SPST switch or switch/limiter as discussed previously. In general, the quasi-solid-state receiver protector acts like an all-solid-state unit under normal operating conditions with the benefit of a gas prelimiter to protect it in the event of an overload.

While this approach may be sound in some applications, great care must be taken in the design to ensure that the power-handing capability of the diode section is not marginal relative to the firing threshold of the pre-T/R unit. A device such as this is much more likely to fail catastrophically. Diode burnout will be the immediate result in a device with a pre-T/R unit that misfires due to insufficient radioactive priming or fails to fire at a low enough threshold due to gas cleanup. Further, since the pre-T/R structure does not provide good out-of-band filtering, this design approach may not provide adequate protection against high power spurious harmonic signals from the transmitter or out-of-band signals from other radar systems. This shortfall could result in catastrophic failure of the receiver protector and/or the receiver itself.

THE PRE-T/R, T/R LIMITER

The traditional receiver protector structure is composed of a pre-T/R tube, a T/R tube and a diode limiter. The T/R tube has an inherently long recovery time. However, recent advances in technology have made it possible to sharply reduce the recovery characteristics of the T/R tube. Thus, the pre-T/R, T/R limiter (TRL) is another viable technology for some applications requiring fast recovery times at high power levels.

The main benefit to the pre-T/R, TRL approach is cost. As a building block, the T/R tube provides the best value from a cost vs. protection point of view. Further, when used in this structure, the pre-T/R and diode limiter sections can be scaled down (and less costly) versions of the ones discussed previously. Another benefit of this approach is that the T/R tube is an inherently good filter for both harmonic and spurious out-of-band signals. Thus, using this type of receiver protector may reduce substantially or even eliminate the need for such filtering by other means. At the end of the day, the pre-T/R, TRL often can be a good alternative that will meet requirements for lower development and unit costs.

CONCLUSION

This article has introduced the core technologies that are now being employed in modern receiver protector designs. The actual choice for a particular application will always be driven by the specification requirements and the design trade-offs involved. The goal for the future is to reduce or eliminate radioactive priming, increase operating life and lower cost. ■