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# Threats and protection for electronically-steered array radars

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ABSTRACT

Front-end power overload protection is a vital issue in any electro-magnetic sensor. The issues around active electronically-steered arrays are more recent and pose new threats. Different categories of threats can damage the sensitive electronics in the phased-array radar, like hostile high power electro-magnetic (HPEM) pulses or the radar's own transmitted signal. Protection measures can be integrated in different parts of the radar system. To obtain an effective EM protection mechanism it is crucial to distribute protection measures over all relevant system parts. Experimental research and development is carried out on front-end protection mechanisms in the radome with frequency selective surfaces (FSS), the antenna face and in front-end electronics by solid-state absorptive limiters and the design of key components, like low noise amplifiers and switches in robust gallium nitride technology.

## INTRODUCTION

Modern phased-array radars on a variety of platforms use electronic beam steering and have sensitive electronics in transmit/receive (T/R) modules. The receive module of a radar is a very sensitive piece of electronics, which needs to be protected against power overload to prevent degradation or damage. In this paper power overload is divided in different threat categories and origins (both hostile and friendly).

Distributed front-end protection measures for active electronically-steered array radars developed and studied at TNO are proposed in this paper.

## THREAT CATEGORIES

To be able to protect the platform against threats it is first necessary to know the threat origins and the possible damage that can result in the radar's front-end. Electro-magnetic (EM) threats for phased-array radar front-ends can be classified according to threat origin and according to the resulting damage. The classifications are presented in this section.

Threat origins can be distinguished by man-made and not-man-made origins. The man-made origins can be classified by:

- Friendly signals from the system itself. When the transmitted signal from the system itself is reflected by a large surface on a relative short distance the receiver will receive a high power reflection from that surface.
- Friendly sources from the platform itself. Different radars located on the same platform can disturb each other.
- Friendly sources from other platforms. This can occur in a harbour when a neighbour ship did not switch off their radar system. The transmitted power will go directly into the radar's receiver.
- Hostile sources. In a hostile environment high power electro-magnetic sources can be used to damage the radar. For example by a high power electro-magnetic (HPEM) pulse or by jammers.

Among not-man-made threat origins weather influences can be counted. For example thunderstorm lightning is a very high power EM source.

The mentioned threat origins can result in different kinds of damage. Damage can be classified in:

- Degradation of the overall system performance. The effective noise figure of the receiver will become higher and the radar's beam will deteriorate.
- Individual T/R module breakdown. This result in a decreasing transmitted power, increasing noise figure and the antenna beam will become wider.
- Simultaneous failure of all T/R modules, resulting in total system failure.

## DISTRIBUTED PROTECTION

For effective and robust protection of active electronically-steered array radars against the previous described threats, measures have to be taken into account in the complete radar receiver system.

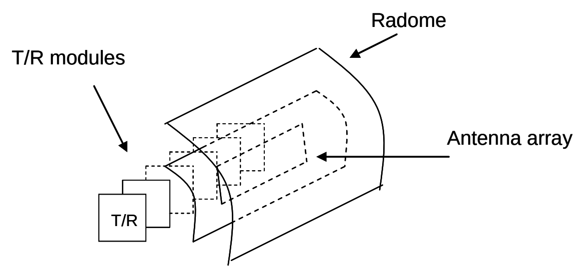


Figure 1: Simplified representation of a phased-array radar front-end

Figure 1 presents a principle schematic of the active electronically-steered array radar front-end elements. A distinction can be made in three levels of protection. Protection measures from the outside to the inside of the radar can be employed in the radome, the antenna face and in the receiver electronics. The so called out-of-band signals can be protected effectively by the radome and the antenna face. But the radome and antenna face have to be transparent for signals in the radar's receive bandwidth (= in-band signals). For the in-band signals receiver protection measures can be employed in the front-end electronics.

## PROTECTION MEASURES: RADOME AND ANTENNA FACE

Protection measures in radome and antenna face are discussed in this section. From the outside to the inside of the system the following measures can be taken.

### *Electronic curtain*

An electronic curtain can cut off the electronic-steered array system from the environment. For example when a fighter aircraft is standing at an airport the electronic curtain has to be switched on to prevent any damage by (friendly) sources, like the radar of a neighbour fighter aircraft.

### *Frequency selective surface*

Frequency selective surfaces (FSSs) are metallic radomes consisting of periodic planar arrays of metallic patches or slot etched on a metallic plane sandwiched between dielectric slabs.

As protecting module, the FSS is designed to be transparent in the operating frequency band of the antenna and to block the incoming signal at frequencies outside this band, as shown in Figure 2. The frequency of operation of such an FSS can be changed (reconfigurable FSS) by using switches, for example positive intrinsic negative (PIN) diodes or micro electro-mechanical systems (MEMS).

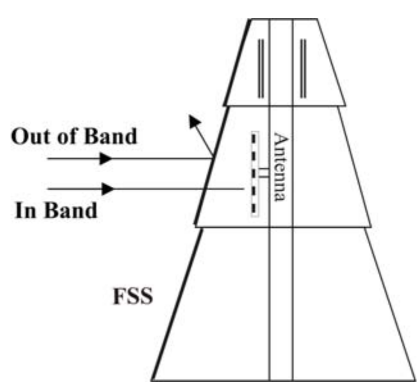


Figure 2. Simplified schematic an FSS application

At TNO an efficient analysis and design technique has been developed for complex multi-layer FSSs both standing alone and integrated with phased-array antennas (reference [1]). This technique has been successfully applied to the design of filters for different applications and the reconfigurability is also currently under investigation.

*Antenna*

The bandwidth of the antenna is an effective protection element. Out-of-band signals can be filtered effectively by the narrow-band waveguide inputs of the antenna elements.

## PROTECTION MEASURES: ELECTRONICS

A schematic diagram of a typical transmit/receive module of an active phased-array radar system is presented in Figure 3. Protection for high power in-band signals have to be applied before the electronics of the receiver. In a conventional system the transmit/ receive module (T/R module) is protected by a reflective limiter and a second circulator to prevent the power reflected by the limiter goes into the transmitter and damages it.

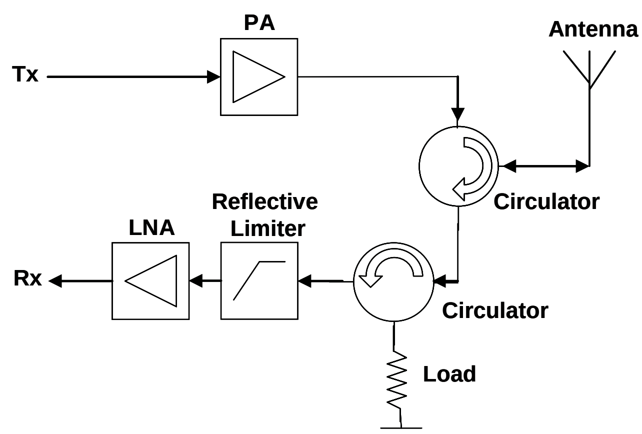


Figure 3. Simplified block schematic of a conventional radar T/R module

The much used circulator is an expensive and large component. It introduces relative high insertion loss and is incompatible with surface-mount technology. A substitute for the extra circulator with a reflective limiter is an absorptive integrated limiter, based on Schottky diodes. Schottky diode limiters are faster than the much used PIN diode limiters and due to the absorptive characteristic the transmitter will not be damaged by reflections, due to the absorptive character. Thereby a solid-state limiter, based on Schottky diodes can be integrated with an LNA in the same technology, which cancels interconnect losses between the limiter and LNA.

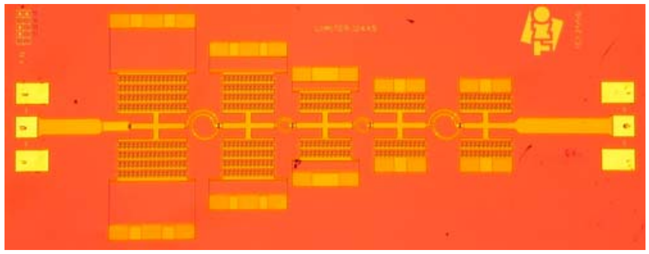

Figure 4. Microphotograph of an integrated limiter MMIC (1.2 x 3.0 $mm^2$)

Experimental research is carried out on different types of absorptive solid-state limiters, based on different principles (reference [2]). The limiters can be made passive (diodes) and active (FET based switches). The limiters are designed in commercial available monolithic microwave integrated circuit (MMIC) technologies.

The development and analysis of key components of T/R modules in gallium nitride (GaN) technology has been performed successfully in the last years and research is still going on. GaN technology provides very robust (compared to gallium arsenide (GaAs)) and sensitive receivers, which even can be made a limiter as a first component in the receiver chain unnecessary. This development will have a positive influence on the radar performance (sensitivity/robustness trade-off), because a limiter is a lossy component.

GaN technology is a popular candidate to develop single-pole-double-throw (SPDT) switches. SPDT switches can be a low cost and integreable substitute for the second circulator (see Figure 3) to switch the radar T/R module operation in transmit or receive mode.

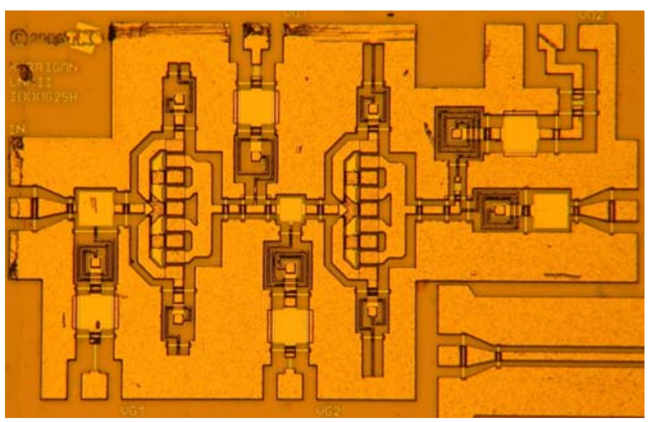

Figure 5. Microphotograph of a GaN low noise amplifier (2.4 x 1.5 $mm^2$)

## CONCLUSIONS

Experimental research is carried out on distributed protection for front-ends (T/R modules) of phased-array radars. The achieved results are promising to improve the robustness/ sensitivity trade-off for modern phased-array radar platforms.

Radomes designed as spatial filters (FSS) can be used to further improve the protection of phased-array radar front-ends for out-of-band signals.

A set of X-band absorptive integrated limiters is successfully designed as protection for high power signals in the radar's bandwidth. The development of receiver and transmitter key components in GaN technology is promising for a robust phased-array front-end with a comparable sensitivity.

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