Cooperation and competition of solid state and vacuum microwave devices in radar applications

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In recent years significant attention is attracted to employing of GaN solid state devices in radar applications. They demonstrated impressive progress in output power and reliability. For example, single GaN transistor has achieved output power level 300 W in X-band with power added efficiency 37% [1]. Connection of such perfect performances with active electrical scanned array (AESA) concept apparently makes possible to create radars in centimeter wavebands quite competitive in power with designs based on TWT and klystrons. As result a new concepts of high power radars are discussed like Space Fence radar, which contains 36000 of transmitting modules of total power 2.69 MW (average – 0.81 MW) in S-band [2].

It could be seemed that the epoch of vacuum tubes in radars tends to end. However, comparing radars based on solid-state and vacuum amplifiers, we must take into account additional features.

As rule, AESA radars are much more expensive comparing vacuum counterparts with passive ESA.

Important radar's parameter is velocity of beam control, which influences a number of simultaneously handled targets. In radar, based on vacuum tube and passive ESA, the beam is usually controlled by ferrite phaseshifters. These unique components possess extremely small microwave losses and high power capability. However, their typical phase switching times are rather large – tens of microseconds. In AESA phase commutation is implemented by solid-state switches having switching times units and tens nanoseconds. So fundamentally solid-state AESA can process larger number of targets than traditional ESA using vacuum devices (if it is not limited by digital part of radar). Taking this fact in mind we can conclude that the opportunity of surviving of vacuum devices in competition with solid-state ones in radar applications of centimeter bands is based on development of fast phaseshifters having small microwave losses and high power capability. The most probable candidates for this role are phaseshifters based on MEMS switches (the switching time 0.2–0.5 us) [3–] and ferroelectric phaseshifters [6, 7].

Besides this very remarkable feature of AESA is the absence of frequency and directional selectivity of each single module. This means that the circuit of each module receives all interference signals from hemisphere. This implies requirement of very large linearity and dynamic range of the receiver (~120 dB) which is not so easy to realize. This means that AESA possesses increased vulnerability to countermeasures and interferences. Contrary to AESA passive phaseshifters in ESA have very large dynamic range (they handle output power of own transmitter), and active devices in receiver after summation circuits are protected by directivity of the array which possesses suppression of side lobes by ~30 dB.

The problem is closely related with protection devices of radar receiver. In AESA solid-state protection devices are not very effective due to strong limitations in volume and mass. They have rather long recovery time and significant transmission at high power levels. In contrast, single receiver in passive ESA can be very effectively protected by vacuum cyclotron device [8, 9] – another superior vacuum device for radar applications.

Nevertheless, along with competition we see also examples of good cooperation of vacuum and solid-state microwave devices. Increasing of output power of solid-state amplifier have made possible to decrease significantly requirements for gain of vacuum amplifier which results in remarkable decreasing of mass and dimensions of the tube. As example we can point out to wideband, small gain TWT (booster) - the foundation of microwave power modules (MPM) – high power amplifiers, which are fabricated not for some specific application but for common use in various systems. Such concept of component-of-the-shelf (COTS) significantly decreases expenses and terms of the development of new radar systems.

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