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Compact radial combiners for broadband high power applications

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ABSTRACT

Multi-way, radio frequency (RF) and microwave power combiners and dividers (splitters) are important components of rapidly developing high power RF and microwave systems used in radars, communication, directed energy, air traffic control, and scientific facilities such as particle accelerators. Several 21-way L-band combiner configurations of a reactive-radial type with enlarged bandwidth, reduced dimensions for high power applications are analyzed numerically: with smooth air gap, solid dielectric filling, and air gap with wiggling radial walls. The last example employs slow waves enabling size reduction and offers significant increase of bandwidth up to an octave and above at low insertion losses.

1. Introduction

Solid-state Radio Frequency (RF) amplifiers revolutionized both RF and microwave high power technologies for industrial, research, defense, and space exploration applications including long range space RF communications. Middle and high power vacuum devices, such as magnetrons, klystrons, traveling wave tubes (TWTs), and inductive output tubes (IOTs), have been traditionally used, in both pulsed and CW modes. Despite of ubiquitous use of high-power vacuum tubes, there are a number of disadvantages compared to Solid State sources: high voltage (HV) power supplies increases the size, complexity, and weight; it is subject to arcing and significantly limits reliability and safety, and it is sensitive to aggressive environment conditions (humidity, temperature, dust, corrosion). The cathode and filament systems limit the lifetime of vacuum tubes. Tubes usually require a considerable time for filament preheating, thus they cannot be switched on immediately, and, in a quasi-pulsed mode, the filament must remain on, greatly reducing power efficiency. The noise is substantial in vacuum devices as they use thermionic emission having inherent statistical noise in the electron beam. The shrinking market of the tubes (most of which were developed in 60s and 70s) across the world is reducing the production base of vacuum devices, imposing higher long-term risks and growing production cost (unlike solid-state devices) as the technological base narrows. Tubes, and especially TWTs, are also sensitive to vibrations, which is critical in many industrial, space and defense applications.

One of the approaches applied to partially mitigate the problems of vacuum tubes is to integrate a solid-state preamplifier and TWT amplifier in a single module called a microwave power module (MPM). L3 Communications has applied MPMs for Unmanned Aerial Vehicles (UAV) communications [1].

Combining is acknowledged as the key technology for attaining high power in a solid-state device especially in a broad band [2]. We outline here multi-way (>15), in-phase radial structures [3,4] that are usually rather effective in HF-X bands with insertion losses typically less than 0.3 dB and bandwidths <20% (for RF and microwave bands) [5]. Note classical radial combiners of a "mushroom" shape [6–8] usually contain a rather small local air gap resulting from impedance transformation. Potential issues related to the narrowed gap may impose more stringent fabrication and assembling tolerances, lower limits on maximum power and/or bandwidth.

Below we consider several electromagnetic designs for a 21-way L-band combiner of reactive-radial type tailoring substantial bandwidth and power handling, reasonably low losses and reduced dimensions. Most of EM design simulations have been performed with HFSS software from Ansoft [9] for 1/21th sector of the design. Some of the designs were modeled without using the 21-way symmetry using CST Studio Suite™ [10] for imbalance control or thermal simulations. Air gaps are assumed to be everywhere at normal conditions (atmospheric pressure $p = 1760$ Torr). For most of the designs we assume by default 1-5/8" EIA-type central port and 21×N-type peripheral ports to handle at least 4 kW CW output (combined) power.

2. Radial combiners of arc and "bottle" types with smooth air gap

A 21-way L-band divider have been designed and tested [11,12] for CW 8 kW klystron replacement [13]. The arc-radial type divider employs SMA type connectors for peripheral ports and N-type connector

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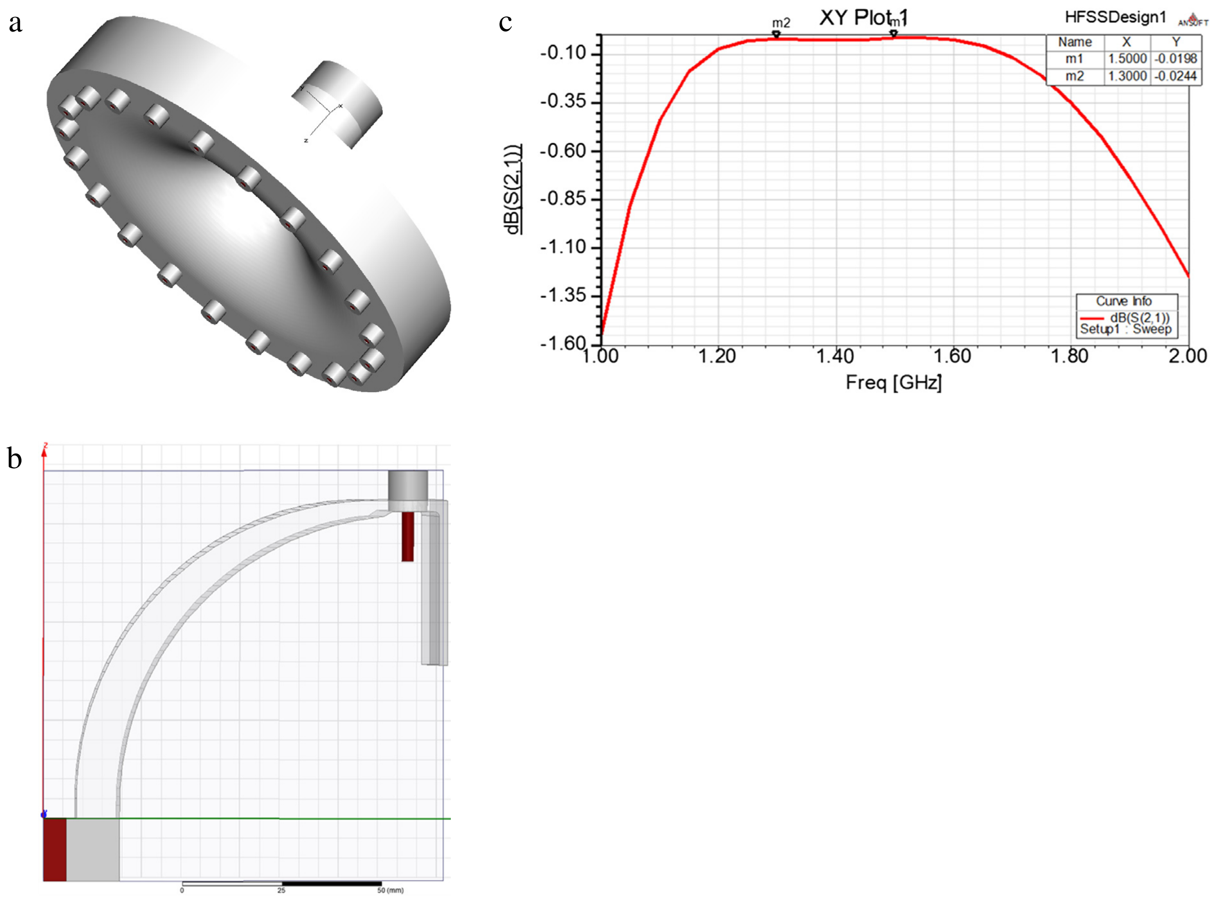

Fig. 1. 21-way arc-type combiner designed for 1.5 GHz frequency, N-type inputs, and EIA-1-5/8-type central output port: "negative" volume view with solids of the 50 Ω coaxial ports (a); Model view for 1/21th sector (b); Insertion loss as a function of frequency (c) simulated for the 1/21th sector (c). The model diameter is 206 mm and height is 104 mm.

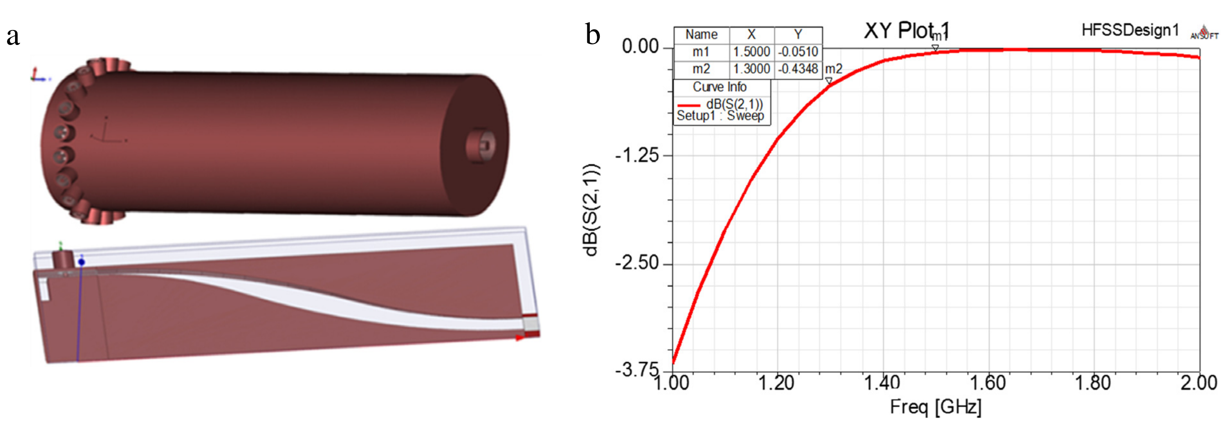

Fig. 2. "Bottle" type 21-way divider having SMA peripheral ports, N-type central port (a) and insertion loss as a function of frequency (b). The model length is ~125 mm.

for central port. One useful feature of that design is adiabatically smooth tapered radial gap (i.e. without a bottleneck gap between the central coax and radial transmission line of the "mushroom" periphery). Therefore, for initial design of the radial combiner we adopted the same arc type combiner having smoothly tapered air gap.

The air-gap design of the optimized arc type combiner and its S-parameters are given in Fig. 1. The design provides about 60% bandwidth at 0.5 dB insertion loss. Since the gap in the vicinity of the central port remains large (~11 mm) the corresponding fd parameter is 16.5 mm GHz. Since another breakdown parameter $p\lambda$ is $3.5{\cdot}10^4$ Torr mm the ionization power limit will approach ~10^4 W [14], which is about twice the standard CW power limit for the EIA 1-5/8" connector (~5 kW at 1.5–2 GHz). For the periphery ports the air gap is 2.81 mm in the vicinity of the Teflon insulator of the bulk head mount of N-type connector. That gap corresponds to the fd parameter 4.2 mm GHz. According to the breakdown curves [14] that imposes again as high as ~10^4 W power limit exceeding by more than an order the power limit for N-type connector (~900 W at 1.5 GHz) and ~200 W anticipated input power per port.

We have also considered here another variant of a broadband radial combiner (or divider) with adiabatically smooth air gap. A "bottle" type configuration illustrated in Fig. 2 applies Klopfenstein matching [15] and enables ~44% bandwidth.

Both configurations above offer substantial bandwidths and comparable power handling capability due to close i/o air gaps (if adapted to the same connectors). However, substantial dimensions of the designs