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A customized reduced size Antipodal Vivaldi Antenna used in Wireless Baseband Transmission for short-range communication

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ABSTRACT

An Antipodal Vivaldi Antenna (AVA) with a reduced size of 37 mm × 21 mm has been designed, simulated and fabricated on 1.6 mm-thick FR4 substrate for ultra-wideband (UWB) applications. It is customized with a slot resonator located on the ground plane only and with a shift of the ground plane input. AVA simulations and measurements are presented and are in good agreement. The antenna exhibits a voltage standing wave ratio of less than 2, and a peak gain in the −0.5 to 4.5 dB range through the 3.6–12 GHz frequency range. The antennas were arranged in an emitter-receiver aligned configuration with a distance $R = 1$ cm, in order to send and receive digital data directly at 1 Gbps with 20-bits input data, based on the Wireless Baseband Transmission (WBT) scheme with Manchester and Polar RZ encodings. Measurements show the recovery of the input digital signals after processing of transmitted output signal and are encouraging to use broadband AVA with a linear phase characteristic as a possible candidate for use in short range communication in cryogenic environment.

1. Introduction

The increasing demand of data transmission rates, in particular for processing signals on microwave carriers, for instance for satellite telecommunications, requires the development of specific circuits and antennas. In particular, some systems that require fast processing at clock rates above 20 GHz rely on superconducting Rapid Single-Flux Quantum (RSFQ) digital circuits to process the signals [1,2]. For such circuits, which are cooled at the temperature of liquid helium, the processed data need to be transferred at room-temperature for further processing. To do so, since the number of wires needs to be limited to reduce the thermal load on the cryogenic system, a wireless link is an attractive solution. The feasibility has already been shown in the 8–12 GHz band [3] for the transmission of microwave analogue signals, like for instance signals at the intermediate frequency of radiofrequency mixers. On the other hand, superconducting digital circuits, for example analogue-to-digital converters that process an instantaneous bandwidth of a few hundreds of MHz, can produce digital data at rates in the range of 40 to more than 100 Gbps per channel. An example of such signals is given in Fig. 1a. In this case the challenge is to transmit digital data without further need of down conversion, in line with the choice of developing all-digital software-defined radio systems. Consequently, after a proper on-chip demultiplexing of digital data to lower the rates in the 1–10 Gbps range, it is preferable to transmit data directly in the base band with small size antennas placed in short distance configuration. The short distance is fixed by the distance between the cryogenic stage at the temperature of liquid helium and the outer part of the cryogenic system at room temperature (see Fig. 1b). We should point out that the broad bandwidth associated to such digital signals does not allow to simply consider that the antennas radiate in far- or near-field, since this feature depends on the frequency. We use the terminology of short distance configuration to discuss the respective positions of the transmitting and receiving antennas.

Since the instantaneous bandwidth to transmit is broad in our case, we investigated the ultra-wideband technology to solve our issue. Indeed, it is a common approach in wireless communication systems to transmit and receive pulses in the time domain, rather than sinusoidal waves processed in the frequency domain [4]. The design is based on Vivaldi antennas, that are popular UWB antennas investigated since 1979 [4–8], and on the Wireless Baseband Transmission (WBT) communication technology. The objective is to transmit the digital data streams from superconducting circuits, after Manchester or polar RZ encodings, directly from an antenna and without any modulation technique [5].

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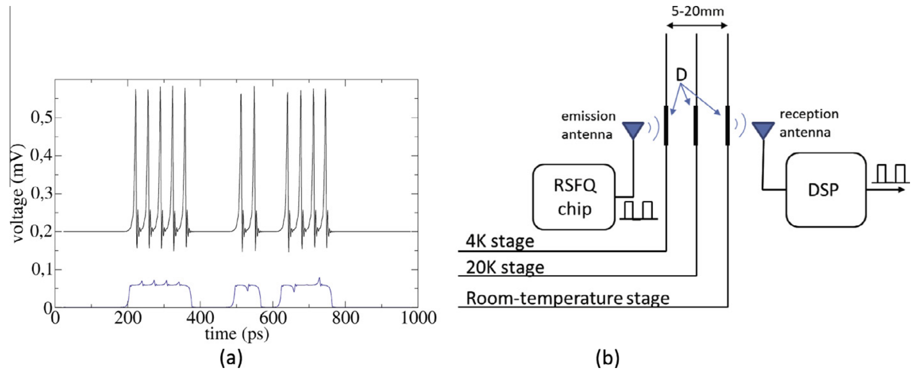

Fig. 1. (a) Typical output digital signal of a RSFQ superconducting electronics circuit. In black the original signal. In blue the intrinsically filtered signal of interest. (b) Block diagram of short distance configuration setup for wireless transmission of digital data from a cryogenic environment. D is the typical diameter of the cryogenic windows, of about 20 mm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Comparison of our customized AVA with some other AVA from the literature.

AVA Ref.	Dimension L ∗ W (mm^2)	Operating frequency (GHz)	Gain (dB)
[6]	60 ∗ 48	2.4 to >14 measured	3.7–10
[7]	40.16 ∗ 42.56	3.1–10.6 measured	−1 to 3.8
[8]	42 ∗ 36	3.7 to >18 measured	1.8 to 6.9
[9]	66.4 ∗ 50	4 to >30 simulated	5–7
This work	37 ∗ 21	3.6 to >12 measured	−0.5 to 4.5

This paper is organized as follows. In section 2, the AVA antenna design is explained. The main properties derived from our needs are described from an analytical approach and compared with some previous work that served as a starting point. Detailed features have been adjusted by simulations. The antenna has been fabricated in a second step, its performance is discussed in section 3. In a further step two AVA were aligned at a short distance from each other to reproduce the final expected configuration. We verified experimentally the proper transmission of digital data streams and present the measurements in Section 4. Finally, we conclude in section 5.

2. Antenna geometry and design

Recently, various antennas have been developed for UWB communications [5–11]. In our case, small antipodal Vivaldi antennas based on elliptical curves have been designed to transmit and receive digital data streams with Manchester or Polar RZ encodings at a data rate above 1 Gbps. Table 1 summarizes the comparison between the proposed antenna and antennas from literature. To fit our needs with the limited space inside the cryogenic system the proposed AVA is smaller in dimensions than the ones with antipodal configuration reported in [6–9]. Besides we optimized it to obtain similar or better performance.

The description of the design of the Antipodal Vivaldi Antenna under concern is given in [12–13]. Two AVAs fed by a 50Ω microstrip transmission line have been designed to be fabricated on a FR4 substrate of thickness h = 1.6 mm with $\varepsilon_r = 4.4$ dielectric constant, and a dielectric loss tangent $\delta = 0.02$ (see Fig. 2). In a second step the UWB range has been improved by adding a slot (Fig. 3). The total size $L \times W$ of the antenna composed of a feed line and radiation flares is 37×21 mm^2. The shape of the flares is designed in the form of elliptical curves. The elliptical configuration presents good broadband characteristics due to the smooth transition between the radiation flares and the feeding line. It is one of the

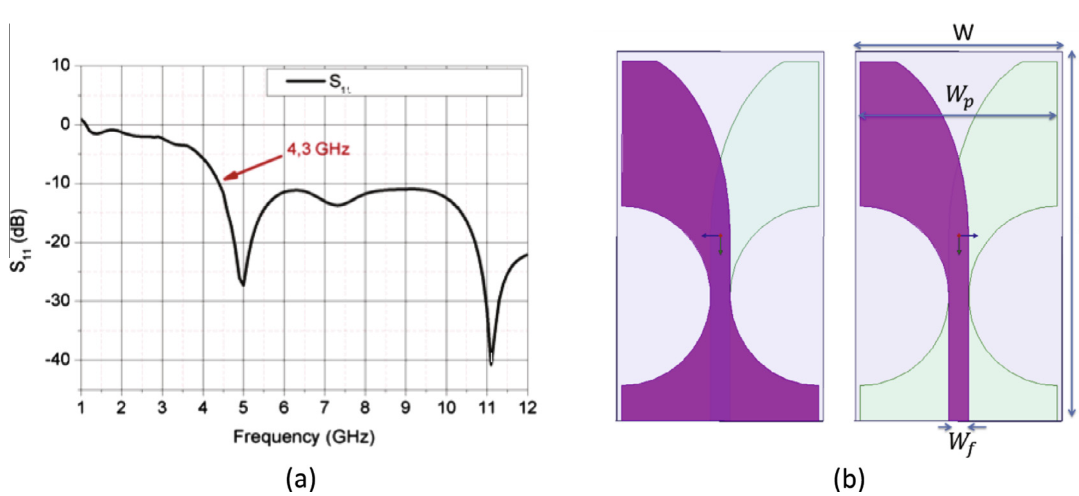

Fig. 2. (a) Simulated return loss and (b) layout of the AVA. Total size ($L * W$) is $37 * 21$ mm^2 on FR4 substrate thickness with h = 1.6 mm, W_f = 3 mm, and W_p = 20 mm.