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Millimeter-wave Cost-effective Screen-printed Log Periodic Antenna

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Abstract—In this paper a wideband cost-effective screen-printed millimeter-wave log periodic antenna is presented. The proposed antenna configuration is implemented using a screen printed process on a 100 μm Zeonex thin film ($\epsilon_r = 2.2$ and $\tan(\delta) = 0.009$). The metalization layers are made off nano particles silver ink ($\sigma = 3.3 \cdot 10^6$ S/m). Measured performances and simulations are in good agreements (peak measured gain of 6.5 dB and simulated peak gain of 7.5 dB). Overall size of the printed prototype is 15x20 mm². The obtained results demonstrate the feasibility of cost-effective high-performances screen printed millimeter wave antenna.

Index Terms—Screen printing, millimeter waves antenna, antenna design.

I. INTRODUCTION

The development of the Internet of Things (IoT) in telecommunications is a driving force for many research topics such as sensors, energy harvesting, antenna design. In parallel with the IoT, the development of flex electronics is taking an increasing place in the design of innovative components for medicine, research or industry 4.0. In this context, a scientific collaboration between IM2NP and CEA-Liten has been set up in order to test the potential offered by screen printing technologies on flexible substrates. According to the few recent exceptions, [1], [2], [3], screen-printed antennas on flexible substrates are very limited in the open literature. For frequencies above gigahertz, the most important part of publications mainly deal with inkjet printing process, [4], [5]. However, the availability of new low loss thin films such as Zeonor [6] and the continuous improvement of screen printing processes, enable the design and production of passive circuits by screen printing up to millimeter frequencies. In this paper the design and implementation using screen printing process of a millimeter-wave Log-periodic antenna is presented. The paper describe the manufacturing process in order to print the antenna and its limitations. Then the antenna design is presented with it's particularity to meet the design rules involved by the screen printing process. The Log periodic antennas printed by the CEA has been characterized in the IM2NP research center. Measurements show a good concordance between and simulations.

All simulations are obtained using the commercial software HFSS 2022-R2 from the company ANSYS using the finite element method.

II. SCREEN PRINTING PROCESS AND METALLIZATION LAYERS THICKNESS OPTIMIZATION

A. Screen printing process

The technology developed by CEA Liten allows to print by screen-printing patterns on various substrates by depositing a metallic or insulating ink through a stencil. In our study we aim to maintain relatively low cost technologies, so we only use textile weave stencils. They are made of a fabric whose the weft is characterized by a thread density and a thread diameter. There are a number of parameters influencing the resolution. In summary, an improvement in resolution systematically requires thinning the metallic layers which causes more conductive losses. Therefore a trade off needs to be found between resolution and thickness of the printed conductive patterns. In addition, the machines used require turning the sheets over between printing on both sides. Thus, an alignment error between the two faces up to 150 μm is difficult to avoid. Moreover, to design an antenna in the millimeter-wave frequency range, the substrate must be very low-loss. Thus a 100 μm thick zeonex film ($\tan(\delta) = 0.0009$ and $\epsilon_r = 2.2$) has been chosen [6]. Finally, to ensure good adhesion of the ink with the substrate, it is necessary to perform a plasma-based surface treatments.

B. Metal layer thickness

We are concerned by the optimization of the feeding lines that we will be used to feed the designed antennas. To screen print the conductive parts of the antenna a nano-particles silver ink ($3.3 \cdot 10^6$ S/m) is used. With such ink, lines spaced of a minimum of 200 μm with 100 μm width can be printed with accuracy with a thickness up to 5 μm . Simulations shows that thinner conductive layers allowing a better printing accuracy results in much more losses and thicker layers induce a significant degradation of printing accuracy. A rapid design of coplanar waveguide or grounded coplanar waveguide shows that a characteristic impedance close to 50 Ω cannot be achieve with printing rules of the used process. Thus, micro-strip lines has been chosen. Simulations of designed micro-strip lines on the zeonex substrate show a reasonable trade-off between printing resolution and losses for a 50 Ω micro-strip line.

III. ANTENNA DESIGN

Fig. 1 shows a top view of the antenna including a south west end launch connector. The antenna is designed in three steps. The first uses standard design procedures available in the literature such as in [7]. Those design rules involve the use

of a short circuit which cannot be realized by screen printing at high frequencies. In addition a feeding solution must be found. To feed the antenna, a 50Ω micro-strip line is designed with ground plane and an end launch 1.85 mm (V) DC to 67 GHz connector from Southwest Microwave connector. The short circuit is replaced by an open circuit.

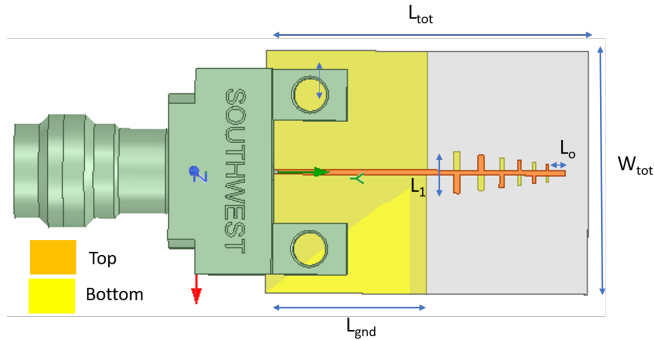


Fig. 1. Proposed log periodic antenna : simulation model.

Distance between end launch connector and antenna (L_{gnd} in fig. 1) and the open ended line length that end the antenna (L_o in fig. 1) are optimized in order to have the wider antenna bandwidth and maximum realized gain. In addition the lower cut off frequency of the antenna can be set by the length of the first element of the antenna (L_1 in fig. 1). After optimization the geometrical parameters of the antenna are $L=20 \text{ mm}$, $W=15 \text{ mm}$, $L_1 = 2.56 \text{ mm}$, $L_o = 1 \text{ mm}$ and $L_{gnd} = 10 \text{ mm}$. The simulated results is shown in fig. 3. A maximum gain of 7.5 dB with -3 dB bandwidth of $45 - 52 \text{ GHz}$, while maintaining good impedance matching in the band. A radiation efficiency of 68% is computed using full-wave simulations.

IV. RESULTS AND DISCUSSIONS

Fig.2 shows a real size photograph of the antenna with 50 cent coin. Antenna measurements are performed with a free space test bench using a MS4647B 4 ports 70 kHz - 70 GHz Anritzu VNA and a QRF67 RFspin reference antenna. 3.

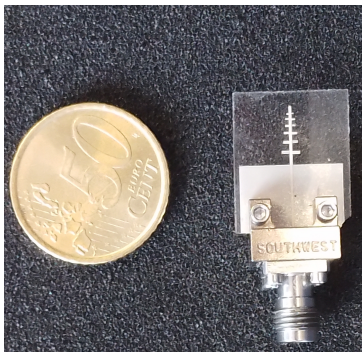


Fig. 2. Real size photograph of the prototype including connector.

Measurements of the screen printed antenna is presented on fig3. Simulations and measurements are in good agreements.

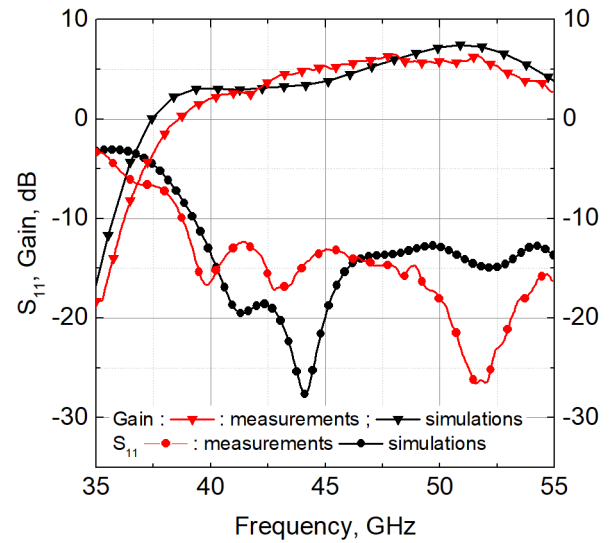


Fig. 3. Measured and simulated gain and reflection coefficient as a function of frequency of the proposed log periodic antenna

The antenna is matched from 37 GHz up to 55 GHz . Measured maximum gain is 6.5 dB and the -3 dB gain bandwidth is 42.5 to 55 GHz . A mismatch of only 1 dB can be observed between measurements and simulations. The achieved performances demonstrate the feasibility of cost-effective, full screen printed millimeter waves antennas.

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