Modeling of Matching Load for Slotted Waveguide Antenna

Bojan Milanović, Stefan Filipović, Vladimir Đorđević and Vladimir Petošević

***Abstract*—In order to reduce simulation time, waveguide matching load with rectangular shape is proposed. Matching load is modeled as dielectric layer with losses introduced via imaginary part of the layer's relative permittivity and permeability. In order to estimate quality of the proposed shape, WIPL-s technical support modeled for us pyramidal shape waveguide matching load, which we used as the reference. All models are made in the WIPL-D PRO-16 software. Rectangular shape is proposed in order to reduce boundary area which has led to reduction of number of unknowns. Comparing the execution time it was shown that by modeling the load as rectangular shape dielectric layer, pattern deviation less than 0.5dB is obtained, while simulation time is noticeable reduced.**

***Index Terms*—Waveguide matching load; slotted waveguide antenna; travelling wave; WIPL-D.**

I. Introduction

Slotted waveguide array antenna, firstly was made in Canada, during the Second World War. At the beginning, it was used in military ground and airborne radar systems for target detection and tracking. Afterwards, application of slotted waveguide array antennas spread to many applications such as: remote sensing from aircraft and space vehicles, microwave communication links, weather forecasting, environmental monitoring, climate change studies, etc. Application of the slotted array antenna for automobile collision avoidance systems is also considered [1]. Broad spectrum of application of slotted waveguide antennas is due the simple structure, suitable for mass production with low cost, simple feeding, precise control of aperture distribution and low loss [2, 3, 4]. Slotted waveguide antennas are often used in radar systems because of high gain requirements and mechanical robustness [5].

There are two types of slotted waveguide array antennas: arrays with standing wave, and arrays with traveling wave [5]. Standing wave array antennas are closed with conducting wall, producing reflected wave due which standing wave is formed. Travelling wave antennas are closed with waveguide matching load. No reflections are produced so no standing wave is formed. Advantage of the travelling wave solution is broader bandwidth.

In order to familiarize with behavior of a radar antenna, model of a slotted waveguide antenna array was built. Idea was to generate and investigate behavior of the antenna pattern for different frequencies, slot angles and to investigate origin of the squint angle. According to the proposal from the WIPL-D technical support, for this research, a matched load with pyramidal absorber is formed. Simulations are started and noticeable length of the simulation time for larger antenna array is noticed. In order to reduce simulation time, alternative solution was needed. According to [6], from the boundary conditions for tangential field components, equivalent electric and magnetic currents placed over the dielectric boundary surface should be uniquely determined. Since the pyramidal absorber has relatively large boundary surface, instead of pyramidal absorber, idea was to reduce surface size by introducing square shaped dielectric layer with corresponding tangent losses. In such manner, shorter simulation time was expected.

II. Slotted Waveguide Antenna

Slotted waveguide antenna is waveguide with a slot on the wider or the narrower wall of the waveguide (Fig. 1). Antenna slot radiates if the slot introduce discontinuity which interrupt the flow of the current along the waveguide. If the current flows around the edges of the slot, the slot will act as dipole antenna [5]. Radiated power from the slot is regulated by tilt angle of the slot. For this simulation and frequency span from 2.9GHz to 3.1GHz, waveguide WR248 (72.136mm x 34.036mm) is used.

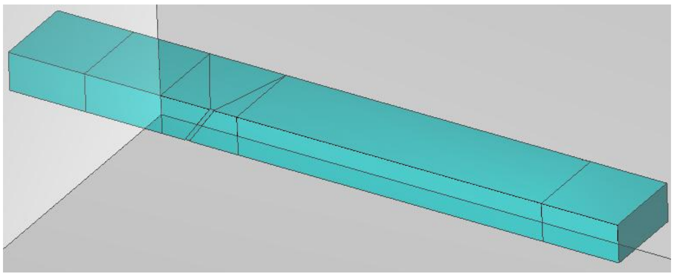

Fig. 1. Slotted antenna with the tilted slot on the narrower side.

Length of the slot should be equal to the half of the free space wavelength. Since this length is larger than the length of the narrower wall, part of the slot is edged (Fig. 2) in to the top and bottom walls [1].

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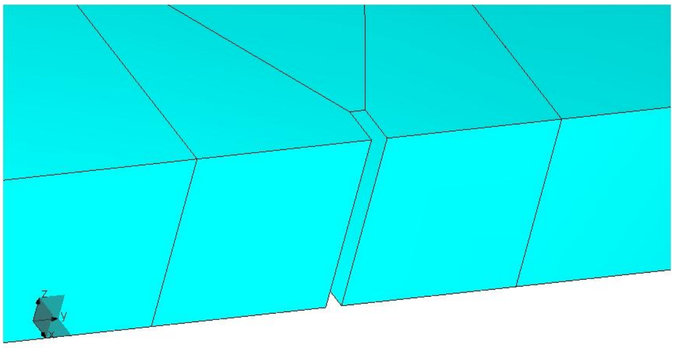

Fig. 2. Waveguide slot edged in to the wither wall.

In order to obtain travelling wave, antenna is closed with matching load (Fig. 3.), proposed from WIPL-D technical support [7].

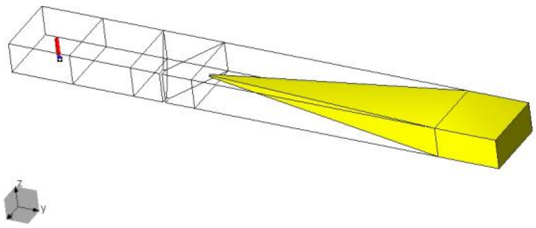

Fig. 3. Position of the pyramidal absorber inside the waveguide.

Pyramidal absorber is two waveguide wavelengths long, with half waveguide wavelength long cubic shape absorber added at the end. Conductivity of the absorber is set to 3 S/m while the real part of the relative permittivity of the absorber is set to 1.1 and imaginary to zero. Simulation of the model with one slot elapsed for 15.62s[1)]. Pattern of the single slot is show in (Fig. 4).

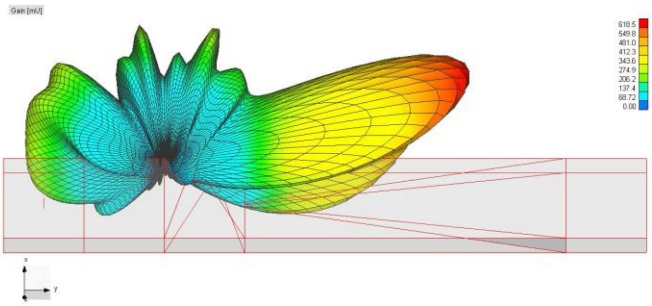

Fig. 4. Pattern of the single slot antenna.

Due to travelling wave condition, pattern is slightly tilted toward waveguide, so in practice, in order to obtained pattern perpendicular to the waveguide, two of this slots are set half wavelength apart, with opposite directions of the tilt.

Model of antenna with two tilted slots is shown in Fig. 5. Simulation time for this array was 34.91s.

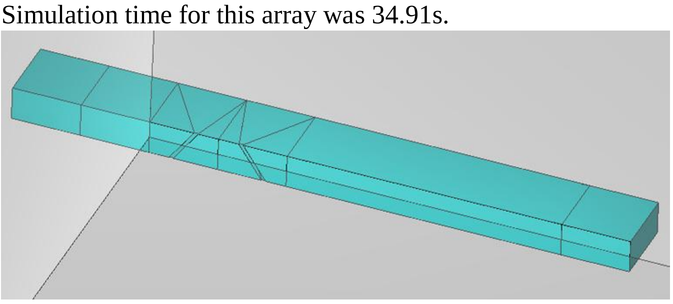

Fig. 5. Two slots antenna array.

[1)] Processor Intel(R) Core(TM) i5-6200U CPU @ 2.30GHz, 2400 Mhz, 2 Core(s), 4 Logical Processor(s)

Antenna pattern of the two slot array is shown in Fig. 6.

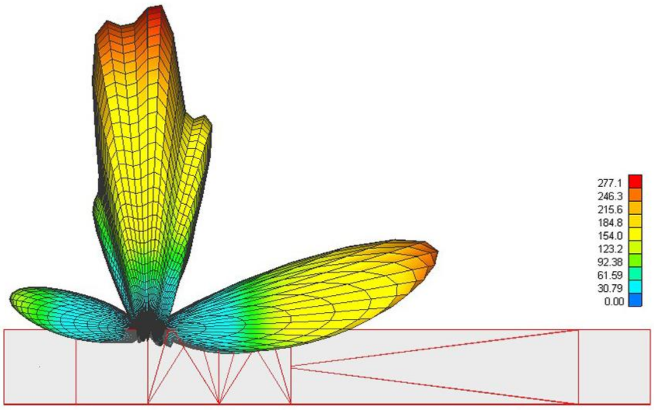

Fig. 6. Antenna pattern of the two slots antenna array.

Simulation for 20 elements antenna array, shown in Fig. 7, elapsed for 117.42s. 2D antenna pattern is calculated for 1441 points in azimuth plane and 1 point in elevation plane.

Fig. 7. Twenty elements antenna array.

Antenna pattern of the twenty slots antenna array is shown in Fig. 8.

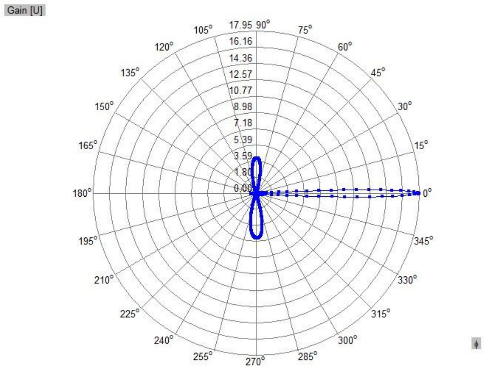

Fig. 8. Twenty elements antenna array pattern.

III. MATCHED LAYER

In order to match short end to the waveguide, absorber with complex relative permittivity and permeability is used. This layer introduces attenuation of the wave passing through, while keeping matched surface with the air. Wave impedance in the waveguide can be calculated by the equation:

$$Z_{TE10} = \sqrt{\frac{\mu_0 \cdot \mu_r}{\varepsilon_0 \cdot \varepsilon_r}} \cdot \frac{1}{\sqrt{1-\left(\frac{\lambda}{\lambda_c \cdot \mu_r \cdot \varepsilon_r}\right)^2}} \tag{1}$$

In order to keep no reflection from the air to dielectric boundary, wave impedance of the dielectric should be equal to the wave impedance of the air. In case of the plane wave, that can be easily achieved by setting relative permittivity and permeability to be equal and by introducing imaginary part with negative sign. But, for waveguide, that is not so easy task, since relative permittivity and permeability appears both in front and under the fraction of equation (1). Since in our version of the WIPL, we don't have optimization tool, relative permittivity and permeability values are obtained by try and error. Idea was to obtain smallest reflection coefficient. In such manner, relative permittivity of $\varepsilon_r = 1 - j \cdot 0.15$ and permeability $\mu_r = 1 - j \cdot 0.15$ are used.

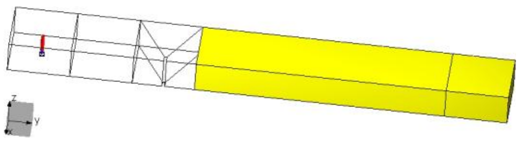

Fig. 9. Rectangular dielectric absorbing layer.

IV. Results

Simulations for single slot, two slots and 20 slots antenna arrays with rectangular dielectric absorbing layer are made. For single slot antenna simulation elapsed for 4.78s compared to 15.62s for model with pyramidal absorber.

In the Fig. 10. antenna patterns for model with matching load modeled with pyramidal shape absorber and matching load modeled as rectangular shape absorber are shown overlaid. From Fig. 10. one can see good matching of these two patterns. Gain difference is of the order part of the dB.

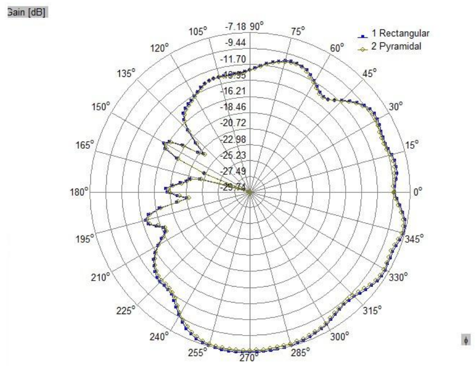

Fig. 10. Single slot antenna pattern comparison.

For two slots antenna array, elapsed time was 6s compared to 34.91s for model with pyramidal shape absorber. In the Fig. 11. antenna patterns for two array antenna model with pyramidal and model with rectangular absorbers are shown overlaid. From Fig. 11. one can see good matching of these two patterns.

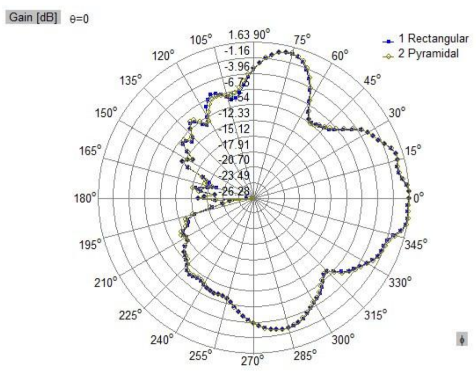

Fig. 11. Two slots antenna pattern comparison.

For 20 slots antenna array, elapsed time was 82.81s compared to 117.42s for model with pyramidal absorber. Same as for previous models, patterns for two different shapes of the matching loads are shown overlaid in Fig. 12.

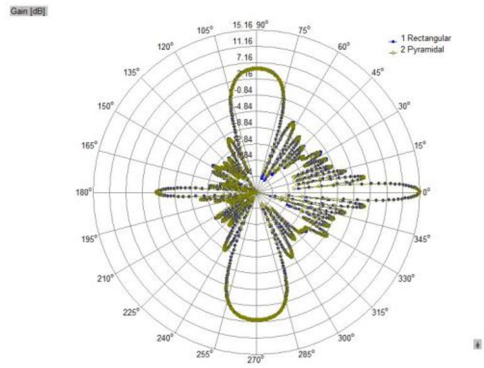

Fig. 12. Twenty slots antenna pattern comparison.

V. Conclusion

By using different shape of the matching load model, simulation time is significantly reduced. For single slot antenna, simulation time is reduced from 15.62s to 4.78s with no noticeable differences in antenna pattern. For two slots antenna, simulation time is reduced from 34.91s to 6s while, for twenty slots antenna array simulation time is reduced from 117.42s to 82.84s. This analysis shows that by reducing total surface area of the boundary between domains, simulation time can be reduced with no significant loss in pattern calculation. Simulations are made for one frequency and single tilt angle of the slot. By taking simulations for many frequencies and many slot tilt angles, this elapsed time reduction become more significant.

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