Antenna Arrays with Slot Open Waveguide Radiation Elements

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***Abstract* - This paper presents designs of antenna arrays with radiating elements formed by sections of open waveguides with longitudinal slots. It has been shown that the antenna arrays can be efficiently used in millimeter wave bands. In particular, 60 GHz band has been considered with the bandwidth of antenna arrays better than 16%. The antenna arrays allow flush installation and can be efficiently used in various communication and remote sensing devices. The number of radiating elements in arrays can be minimized using optimal directivity of the elements caused by uniform field distribution along the slots. The directivity of the 8-element array is 18dBi in 60GHz band.**

***Index Terms* - antenna arrays, millimeter wave bands, slot antenna, flush installation, directivity, open waveguide, conformal antennas**

1. Introduction

The fifth generation of wireless networks is supposed to achieve performance level that far exceed today's capabilities. Since the available spectrum below 6 GHz is nearly depleted, the higher frequencies in the millimeter wave bands draw enormous interests.

The millimeter waves with frequencies above 30 GHz are characterized with very high path losses comparing to electromagnetic waves in low gigahertz communication spectrum bands. To compensate the losses the millimeter wave technology should use antennas with high directional gain. Well known dipole and patch antennas can be good candidates for radiation elements in phased array antennas. The bandwidth requirements can be met by using specific shapes (bow-tie, fractal, oval, etc.) and matching transformers (see [1]). Antennas for high-speed moving vehicles, such as aircrafts, missiles and drones have specific set of requirements. First of all these antennas should allow flush mounting and, ideally, conform the surface of the vehicle. Conformal phase array antennas are often designed using slots of various shapes as radiating elements.

In this paper new wide band millimeter wave antenna arrays formed by conductive cylindrical screens with longitudinal slots are proposed. The radiating elements of the arrays were described in [2]. The cylindrical screens with longitudinal slots are open waveguides that operate in basic H_{00} mode. The H_{00} mode is associated with the low frequency scattering resonances studied in [3]. Since the cross-sectional shape of the waveguide supporting H_{00} mode is very flexible, the cylindrical screens can overlap with a part of the vehicle surface and the antenna arrays have no protruding components.

2. Antenna Configurations

The radiating element of the antenna arrays consists of a metal cylinder and a narrow slot of finite length that was cut-out in the longitudinal direction. Since the radiation is coming from the slot, the antenna can be classified as a slot antenna. However, we do not employ the commonly used concept that the thin slot in an infinite ground plane is the compliment to a dipole in free space, i.e. the slot in the open waveguide antenna is not a magnetic dipole. In essence, the antenna operates more like a leaky-wave antenna and the length of the slot is bigger that $\lambda_0/2$ (λ_0 – is the wavelength of the radiation in free space) (see Fig.1). In contrast with conventional cavity-backed slot antenna designs, the considered antenna design does not use cavity resonances. Conditions to support a fundamental mode of a closed waveguide are not required.

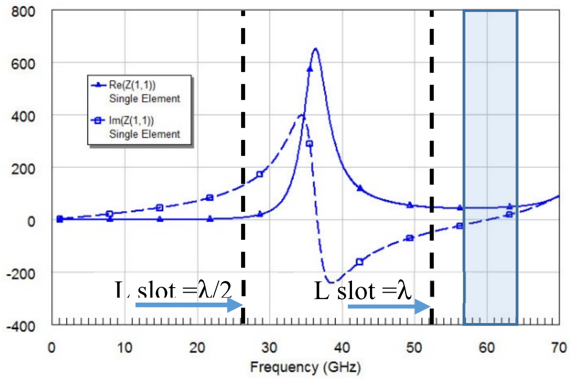

Fig. 1. Input impedance of the antenna element for 60GHz array. Operation range is from 57GHz to 64GHz.

The length of the antenna elements along the slot (X-axis) is bigger than the wavelength at the operation frequency, however the width of the antenna elements (Y-axis) is small. Consequently, antenna arrays can be formed by a number of the antenna elements located sequentially along the y-axis with the slots parallel to each other. The distance between the slots can be chosen as $\lambda_{central}/2$, where $\lambda_{central}$ is the wavelength at the central operation frequency of the antenna array.

Since the slot open waveguide antenna operates like a leaky-wave antenna - H_{00} wave propagates along the slot and radiates into the open space - the field distribution along the slot should be made as uniform as possible. As the result the antenna radiation pattern in the plane that is parallel to the slot (ZX-plane) can be relatively narrow (3dB beam width is less than 45°). We use identical elements in antenna arrays and the dimensions of the slot open waveguide were optimized to make the input impedance very close to 50Ω. Consequently we do not need in any extra tuning and impedance matching components in the corporate feed networks.

3. Results and Discussion

The antenna arrays are formed by a 2, 4, and 8 radiating elements located sequentially along the y-axis with the slots parallel to each other. The dimensions of the 4-element antenna array are 10.668mm, and 7.62mm (L_y, L_x). The dimensions of the 8-element antenna array are 21.336mm, and 7.62mm (L_y, L_x). The thickness of the antenna is defined by the cross-sectional dimension of the cylindrical screens along Z-axis and it is 0.762mm. The optimal slot length is 5.715mm.

In this particular case we design an antenna array that should operate in the frequency band allocated by Federal Communication Commission (FCC) for unlicensed wireless systems from 57GHz to 64GHz. It is supposed to use IEEE 802.11ad communication standard. We need to keep the antenna input impedance close to 50Ω within the operation frequency band. The $|S_{11}| \leq$-10dB bandwidth of the antenna is 16.2% with the central frequency 60GHz. We assumed that the antenna feeds are located at the middle of the slots. An antenna corporate feed network can be designed using microstrip lines that can be located inside the cylindrical screens (see [4]). The antenna array return loss and VSWR as the functions of frequency are presented on Fig. 2. One of the advantages of using the open waveguide mode when the slot length is comparable with the wavelength is that the radiation pattern remains the same at all frequencies within the operation band. The antenna actually operates in vicinity of a single low Q resonance. The directivity of the 4-element antenna array is 15dBi and 8-element antenna array is 18.1dBi. The antenna radiation pattern in the XZ-plane is defined by the electromagnetic field distribution along the slots. The H_{00} mode excited in the open waveguide makes the field distribution along the slots very close to uniform. Consequently the 3dB beam width in XZ-plane is less than 45° (the antenna width in this plane is 7.62mm). The 3dB beam width in YZ-plane is 24.2° for the 4-element array and 11.8° for the 8-element array. The back radiation level is less that -20dB and in case of the antenna flush installation (the upper ground plane is bigger), the back radiation will be reduced. The normalized radiation patters of the 8 element antenna array are presented in the Fig. 3.

4. Conclusion

Antenna arrays formed by sets of slot open waveguide radiating elements are presented for millimeter wave applications, including communication and remote sensing. Basic radiating elements formed by cylinders with longitudinal slots have very good matching properties. As the result, the operational bandwidth of the proposed antenna arrays in 60GHz band can be better than 16%. One of the remarkable features of the considered antenna elements is the optimal field distribution along the slot that results in increased directivity. The slot length of the array elements has been chosen close to the wavelength of the radiation at the operation band central frequency. It was demonstrated that the proposed array with only 8 elements can have the directivity 18dBi. The antenna arrays allow flush mounting and can be installed on high-speed moving vehicle.

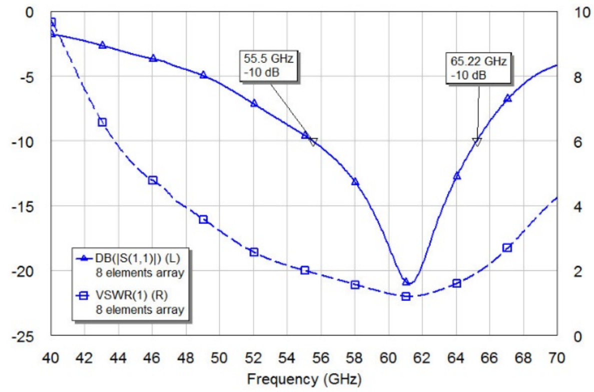

Fig. 2. Return loss and VSWR versus frequency of the 60GHz 8-element antenna array.

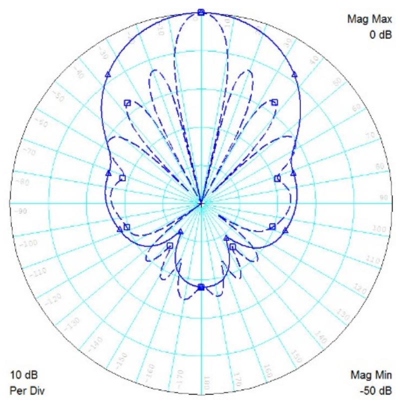

Fig. 3. Normalized radiation patter of the 60GHz 8-element antenna array (solid line –XZ plane and dashed line – YZ plane). The directivity is 18.1dBi.

References

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