Abstract — In the paper, the design of Vivaldi antennas operating in Ka band and W band of millimeter waves is described. Attention is turned to the impedance bandwidth of the antennas. Discussions are focused on the transition of the design in the Ka band to the design in the W band. The designs are supported by simulations in CST Microwave Studio and compared with measurements.

Keywords — Ka band, K connector, W band, Vivaldi antenna, W connector.

I. INTRODUCTION

Today’s wireless communication suffers from the lack of free frequency spectrum. Therefore, communication systems are shifted to higher and higher frequency bands. At higher frequencies, novel design techniques of communication components have to be exploited.

In the paper, the design of Vivaldi antenna operating in Ka band (26.5 GHz to 40.0 GHz) is reviewed [1], [2], [3]. Then, the transition of the design to the bands V (50 GHz to 70 GHz), E (60 GHz to 90 GHz) and W (75 GHz to 110 GHz) is discussed.

The basic design procedure of Vivaldi antenna is reviewed in Section 2. In Section 3, the antenna design in the Ka band is explained. Sections 4 and 5 show the transition to the W band.

II. VIVALDI ANTENNA DESIGN

Vivaldi antenna is a member of a class of aperiodic continuously scaled traveling-wave antennas. Vivaldi antenna is created by an exponential slot in a conductive layer. The conductive layer forms the top side of the dielectric substrate. A proper operation of the antenna is conditioned by the validity of the relation [1]:

$$\frac{h_{d}}{\lambda} = \left(\sqrt{\varepsilon_{r}} - 1\right) \frac{h}{\lambda_{0}},$$  \hspace{1cm} (1)

where $\varepsilon_{r}$ is the dielectric constant of the microwave substrate, $h$ is the height of the substrate, $\lambda_{0}$ is the wavelength in free space, and $h_{d}$ is the effective height of the substrate.

III. VIVALDI ANTENNA FOR KA BAND

Vivaldi antenna was designed and implemented on the microwave substrate ARLON 25N (height $h = 0.788$ mm,
dielectric constant \( \varepsilon_r = 3.24 \), loss factor \( \tan \delta = 0.0025 \) at \( f = 10 \text{ GHz} \). Fig. 2 shows the geometry of the final design of Vivaldi antenna.

![Fig. 1. Vivaldi antenna: the basic geometry.](image)

Vivaldi antenna for Ka band operation is of the following dimensions:

- \( W_1 = 10.140 \text{ mm} \), \( W_2 = 3.240 \text{ mm} \), \( W_3 = 1.816 \text{ mm} \), \( W_4 = 4.490 \text{ mm} \), \( W_5 = 12.712 \text{ mm} \), \( L = 10.140 \text{ mm} \), \( L_1 = 1.511 \text{ mm} \), \( L_2 = 0.900 \text{ mm} \), \( L_3 = 2.987 \text{ mm} \), \( L_4 = 15.538 \text{ mm} \), \( R_1 = 6.690 \text{ mm} \), \( R_2 = 3.450 \text{ mm} \), \( R_{S1} = 10.140 \text{ mm} \), and \( R_{S2} = 1.720 \text{ mm} \).

![Fig. 2. Vivaldi antenna: geometry of Ka band implementation.](image)

The transition from the balanced twin-line to a coaxial unbalanced feed point is implemented using a linear microstrip taper. The unbalanced end of the tapered balun resembles a microstrip line of width \( W_3 (Z = 50 \text{ \Omega}) \) over a finite ground plane of width \( W_5 \). In order to approximate an ideal microstrip line, the ground plane has to be much wider than the metallic strip. In the proposed design, a ratio \( W_3 / W_5 = 7 \) is assumed [4]. In this design, the width \( W_4 \) depends on the opening angle of the strip, and equals to \( a = 6^\circ \) [4]. The length \( L_1 = 0.303 \lambda_g \) [4] and the length \( L_3 = 0.600 \lambda_g \) [4]. Here, \( \lambda_g \) is the wavelength on the micro-wave substrate given by

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\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_r}}
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where \( \lambda_0 \) is free-space wavelength, and \( \varepsilon_r \) is effective permittivity of the microwave substrate. In order to approximate an ideal microstrip line, the ground plane has to be much wider than the metallic strip. In the proposed design, a ratio \( W_3 / W_5 = 7 \) is assumed [4]. In this design, the width \( W_4 \) depends on the opening angle of the strip, and equals to \( a = 6^\circ \) [4]. The length \( L_1 = 0.303 \lambda_g \) [4] and the length \( L_3 = 0.600 \lambda_g \) [4]. Here, \( \lambda_g \) is the wavelength on the micro-wave substrate given by

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The bandwidth defined by the \(-10\) dB decrease of the magnitude of the reflection coefficient at the input of the measured antenna is \(B = 22.43\) GHz. The real component and the imaginary one of the input impedance are shown in Fig. 5.

Measured and computed directivity patterns of the Vivaldi antenna are depicted in Fig. 6.

![Measured and computed directivity patterns of the Vivaldi antenna: H plane (left) and E plane (right).](image)

**IV. W CONNECTOR AND SILICON SUBSTRATE**

Increasing frequency, conventional microwave substrates have been losing required properties and losses have been increasing [6]. Therefore, conventional substrates have to be replaced by highly-resistive silicon.

Moreover, a proper connector and its fixing to the antenna have to be carefully chosen. From the viewpoint of wide impedance bandwidth, exploitation of W connector seems to be a promising solution: the theoretical bandwidth of such solution is 0 to 135.7 GHz [5]. Practically, the bandwidth is limited by 110 GHz. Dimensions of W-connectors are recommended by IEEE Std. 287-2007.

![Geometry of the CST model of W-connector.](image)

In order to develop as accurate computer model of the W connector as possible, most parasitic properties of the modeled structure have to be considered. Fig. 7 shows the geometry of the CST model of two W connectors (Anritsu W1-103F), which are connected by the microstrip transmission line of the characteristic impedance \(Z_0 = 50\) \(\Omega\). Used silicon substrate is of the following parameters: height \(h = 0.1\) mm, dielectric constant \(\varepsilon_r = 11.8\), and resistivity \(\rho = 7\) k\(\Omega\)m.

Frequency response of the reflection coefficient at the input \(S_{11}\) and the transmission of the structure \(S_{21}\) are shown in Fig. 8 and Fig. 9.

![Frequency response of the transmission coefficient of the microstrip line completed by W-connectors.](image)

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![Detail of microstrip to W-connector transition.](image)

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A recommended offset and the dimension of the compensation gap have to be respected. Fig. 10 shows the detail of the connection between the microstrip and the connector manufactured by Anritsu.

**V. VIVALDI ANTENNA FOR W BAND**

Vivaldi antenna is designed considering high-resistivity silicon substrate (height \(h = 0.1\) mm, permittivity \(\varepsilon_r = 11.8\) and resistivity \(\rho = 7\) k\(\Omega\)m). Layout of the antenna is shown in Fig. 11.
W-band Vivaldi antenna is of the following dimensions:

\[ W_1 = 0.4774 \text{ mm}, \quad W_2 = 0.0682 \text{ mm}, \quad W_3 = 0.1230 \text{ mm}, \]
\[ W_4 = 0.1976 \text{ mm}, \quad W_5 = 4.9643 \text{ mm}, \quad W_6 = 0.8487 \text{ mm}, \]
\[ L_1 = 0.3670 \text{ mm}, \quad L_2 = 0.2692 \text{ mm}, \quad L_3 = 0.2936 \text{ mm}, \]
\[ L_4 = 4.6187 \text{ mm}, \quad R_{S2} = 1.5431 \text{ mm}, \quad R_1 = 1.8892 \text{ mm}, \]
\[ R_{S1} = 4.9634 \text{ mm}. \]

Fig. 11. Layout of W-band Vivaldi antenna.

Fig. 12. Geometry of the numerical model of W-band Vivaldi antenna developed in CST.

Fig. 13 shows frequency response of the magnitude of the reflection coefficient at the input of the W-band Vivaldi antenna. The impedance bandwidth of the antenna is 65 GHz. Real and imaginary parts of the input impedance of the antenna are depicted in Fig. 14.

Fig. 13. Frequency response of the reflection coefficient at the input of W-band Vivaldi antenna.

Fig. 14. Input impedance of W-band Vivaldi antenna: input resistance (black), and input reactance (red).

Fig. 15 shows directivity patterns of the W-band Vivaldi antenna computed in CST Microwave Studio for frequencies \( f_1 = 71 \text{ GHz} \) and \( f_2 = 76 \text{ GHz} \).

Fig. 15. Directivity patterns of the W-band Vivaldi antenna at \( f_1 = 71 \text{ GHz} \) (left) and \( f_2 = 76 \text{ GHz} \) (right).

VI. CONCLUSION

In the paper, practical implementation of a wideband antenna for frequencies 71 GHz to 76 GHz is described. The antenna is designed for the high-resistivity silicon substrate. The impedance bandwidth of the designed antenna is \( B = 65 \text{ GHz} \) (compared to 22.4 GHz of the Ka-band antenna).

Experimental verification of technical parameters of the W-band Vivaldi antenna is under preparation.

REFERENCES