Design of microwave antenna system on planar Yagi-Uda elements and microstrip coupler

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Abstract. Paper presents results of calculation, electromagnetic modelling and measurements of manufactured antenna system on planar Yagi-Uda elements and microstrip coupler. System has summary and subtract modes. Center frequency of system is 1532 MHz with 96 MHz bandwidth. Gain of system is 8 dB in main lobe direction (in-phase mode) and 5 dB (antiphase mode).

1. Introduction
Due to progress in information technology increases the need to create specialized transceiver antenna systems for transmission/receiving in the microwave frequency range and having orientation [1]. The paper presents the description of the process and outcomes of a directional antenna system agreed planar Yagi-Uda elements and microstrip coupler with the center operating frequency \( f = 1.532 \) GHz and bandwidth \( \Delta f = 96 \) MHz.

Antenna system has in-phase and antiphase operation modes; each mode has its own indicators of the standing wave ratio (SWR) and the radiation pattern. Design process is divided into 3 phases: geometrical parameters calculation of elements [2, 3], electromagnetic simulation and optimization model using CST Studio Suite, creating a physical prototype, measurement and parameter analysis. The main features of this antenna system include its small geometric dimensions, manufacturing simplicity and planarity, two modes of operation and the possibility of increasing the number of elements to create a prototype of a phased array antenna with preservation of topology.

2. Calculation and modelling
It was originally calculated the geometric parameters of the coupler (Fig. 1) in the equivalent circuit of the ring power coupler (also named “rat-race”) for glass-reinforced epoxy laminate sheet (manufacturer name - FR-4) thickness \( d = 1.5 \) mm with the measured relative permittivity \( \varepsilon_r = 4.67 \) according to the formula (1) [2]:

\[
\frac{W}{d} = \begin{cases} 
\frac{8e^{d}}{\varepsilon_r^{4} - 2} \\
\frac{2}{\pi} \left( \frac{\varepsilon_r^{4} - 1}{2} \ln(2B - 1) + \frac{\varepsilon_r^{-1}}{2} \ln(B - 1) + 0.39 \cdot \frac{0.61}{\varepsilon_r} \right) 
\end{cases} 
\text{for} \quad \frac{W}{d} < 2 \\
\text{for} \quad \frac{W}{d} > 2
\]
Where

\[ A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left( 0.23 + \frac{0.11}{\varepsilon_r} \right) \quad \text{and} \quad B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}. \]

Calculated coupler offshoots have width 2.7 mm \((Z_0 = 50 \text{ Ohm})\), circle width is 1.39 mm \((Z_1 = \sqrt{2}Z_0 = 70.7 \text{ Ohm})\).

![Figure 1. Coupler schematic in CST Studio](image1)

Next it was calculated the planar Yagi-Uda antenna with three directors and balancing transformer (Fig. 2).

![Figure 2. Antenna schematic in CST Studio](image2)

Active antenna driver has a 2 mm width and a length \(l = \lambda / \sqrt{\varepsilon_{\text{eff}}} \); \(\varepsilon_{\text{eff}}\) - effective permittivity, \(\lambda\) – free space wavelength at 1532 MHz frequency. Directors are selected shorter than the driver. Reflector performs a ground in the unbalanced input and microstrip line of transformer; so it has the geometric dimensions: printed circuit board (PCB) width, the length is from PCB border to the distance should be approximately 0.5\(l\). The distance from the vibrator to the directors and between subsequent directors still 0.15\(l\)-0.25\(l\). The lengths of the directors should be less than \(l\). Transformer is made on microstrip lines (Fig. 2, left). The input 50 Ohm line is divided into two with a resistance of 70.7 Ohms, like the coupler circuit. One of the lines longer than the other to \(\lambda/2\), at the junction of microstrip lines pass into coplanar 50 Ohm stripline, gradually passing into slotline impedance of 75 Ohms. At this point, the ground-reflector is interrupted, thereby providing a balanced coordination of the driver of the antenna impedance 73 Ohm [4]. Using CST Studio environment, geometry parameters were optimized. The next step was mirroring elements, with a distance of 100 mm between them, shown in Figure 3. The result of the simulation of the two elements is a graph of the S-parameters as a function of frequency, which is most clearly interpreted voltage standing wave ratio.
(VSWR) dependent on the frequency (Fig. 4), and the gain at a frequency of 1532 MHz for the two modes of operation (Fig. 5, left and right). The geometrical parameters of the microstrip lines are calculated using the formula (1), the calculation of coplanar stripline and slotline - represented in the literature [2]. General view of the system shown in Fig. 3.

![Figure 3. Antenna system main view in CST Studio](image)

**Figure 3.** Antenna system main view in CST Studio

![Figure 4. Results of VSWR for 2 operation modes (model)](image)

**Figure 4.** Results of VSWR for 2 operation modes (model)

As simulation results is bandwidth 228 MHz (assuming VSWR≤2) with center frequency 1500 MHz. The gain for the in-phase mode is 9.4 dB, width of the main lobe 60° (Fig 5, left), the gain for antiphase mode is 7.6 dB (Fig 5, right). Radiation pattern on antiphase mode contains two lobes, deflected to the side of the main line 43°.

![Figure 5. Results of gain for 2 operation modes (model)](image)

**Figure 5.** Results of gain for 2 operation modes (model)
3. Crafted antenna measurements
The antenna system communicated by cable segments with impedance of 50 Ohms, then the device was measured Agilent PNA-X N5247A. Fig. 6 is a plot of SWR of the system, for two operation modes.

![Figure 6. SWR of antenna system](image)

SWR minimums of measured system differ from simulation results to 40 MHz. Bandwidth is 96 MHz on two modes of operation. Measurements of the gain coefficients were carried out in an open space operation with the help of a portable system for the measurement of electromagnetic fields, Rohde & Schwarz TS-EMF. Measured gain for frequency 1532 MHz is presented below (Fig.7), the solid line shows the in-phase operation mode, dashed – an antiphase mode. In-phase mode gain in the direction of the main lobe is 8 dB, the width of the lobe 60°. Antiphase mode gain - 5 dB, width of each lobe 45°.

![Figure 7. Gain of antenna system](image)

4. Conclusion
Antenna system on planar Yagi-Uda elements and microstrip coupler was designed, modelled and manufactured. It supports two modes of operation. Deviation from VSWR model is 40 MHz; bandwidth of crafted antenna decreased from 228 to 96 MHz with a center frequency of 1532 MHz. Lines for the in-phase and antiphase operation modes are identical, it indicates little phase deviation characteristic of coupler. The gain of the system is 2 dB less than from model pattern of the antenna system and made similar to each other. System dimensions range is 135:100:100 mm.
The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

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