

Secondary Surveillance Radar Antenna

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Abstract

The paper deals with the secondary surveillance radar (SSR) array antenna, which is intended for a system combining the SSR antenna and the primary surveillance radar antenna. It describes patch array elements, synthesis for the SSR array considering both elevation and azimuth patterns for sum, difference and sidelobe suppression beams and suspended stripline couplers. The utilization of multilayer techniques allows connection of layers with patch radiating elements and layers with beam-forming networks.

Keywords: Secondary surveillance radar (SSR), array antenna, antenna synthesis, patch antenna, stripline couples.

1. Introduction

Microwave beacon systems transmit pulsed radiofrequency waves to locate targets, using the time delays of the “echo” to determine distances and use directional antennas to determine angular locations. The distinguishing feature of beacon systems is that the target cooperates in this process, using on-board electronics to enhance the returned radiofrequency wave with amplification, frequency shifting, or coding. Beacons are thus highly accurate and reliable surveillance systems and also can provide some data-link capability [1].

The most widely used military beacon system is the Identification Friend or Foe (IFF) system. Secondary surveillance radars (SSR) are civilian systems used in air traffic control (ATC), which not only detect and measure the range and bearing of aircraft but also requests additional information from the aircraft itself such as its identity and altitude. All systems have similar waveforms and share common frequencies of 1030 MHz for interrogation and 1090 MHz for reply. Polarization is always vertical [1], [2] and [3]. The preferred vertical pattern shape for SSR is a modified cosecant pattern, where the upper limit of coverage is typically about 40 deg elevation. Accurate determination of target angle and minimization of false targets are of central importance for the horizontal plane. Usually, surface-based interrogators use a low sidelobe sum (Σ) beam with a 3 dB width of 2 to 4°. A difference pattern (Δ) can be included in the horizontal plane for greater accuracy. That allows angle accuracy of 1 to 2 percent of the half-power

beamwidth. For arrays, the beam is formed with cophased illumination in the horizontal dimension. Amplitude tapering for -25 - to -30 -dB sidelobes is typical. The Δ beam is obtained by feeding opposing sides of the aperture in phase opposition. Use of the Σ amplitude taper for both the Σ and Δ patterns gives a simple feed network but results in quite high Δ sidelobes. This high-sidelobe Δ pattern is suitable only for noncritical uses. A more complex multibeam feed network, capable of producing an independently optimized Δ illumination (such as the Bayless taper) could be used. Optimal Σ and Δ illuminations are very similar on the outer parts of the array, so the multibeam feed is only required for the center portion of the array. The interrogation sidelobe suppression (SLS) for the transponders to avoid replying to sidelobes of the interrogator antenna can be used, when the interrogation is transmitted first by the Σ pattern and then by an omnidirectional pattern with gain lower than the main Σ beam but higher than that of the sidelobes. The transponder replies only if the amplitude for the Σ interrogation exceeds that for SLS by some prescribed margin.

Several microwave beacon systems such as [1], [2] and [3] have been described including arrangements combining primary radars and IFF or SSR systems. At sites which have a large radar reflector as part of the surveillance equipment, a sharp horizon cutoff for the beacon can be obtained by sharing the reflector with the radar, using an integral feed. IFF dipoles also have been added to “flat plate” radar antennas of airborne system (planar arrays of waveguide slots). Thin, carefully tuned dipoles and orthogonal polarization are used to minimize interaction of the two systems.

The paper deals with the SSR array intended for system, which combines the SSR antenna and the primary surveillance radar antenna. It describes a patch array element and synthesis for the SSR array, which uses stripline couplers, considering both vertical and azimuth patterns for Σ , Δ and SLS beams. The utilization of multilayer techniques permits connection of layers with patch radiating elements and layers with beam-forming networks.

2. Array element

According to system requirements, it was necessary to use a patch antenna as an array element. The patch radiating element with multilayers of beam-forming networks is shown in Fig. 1. This structure has been computed and optimized using full-wave simulation. Fig. 2 shows the measurement and numerical simulation of S_{11} reflection coefficient for final design of the

patch radiating element with multilayers of beam-forming networks shown in Fig. 1. A good agreement between measurements and numerical simulations could be seen.

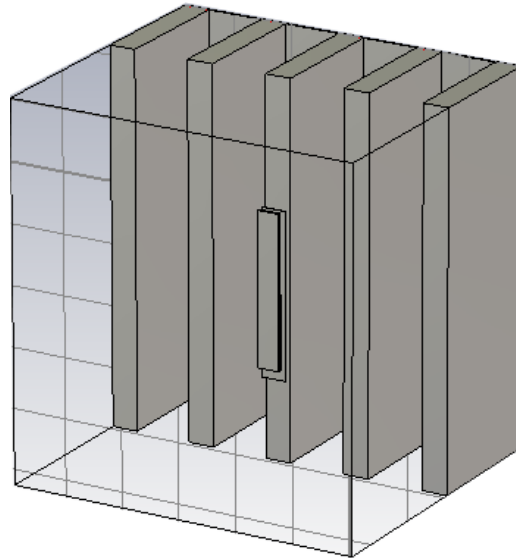


Fig. 1. The patch radiating element with multilayers of beam-forming networks

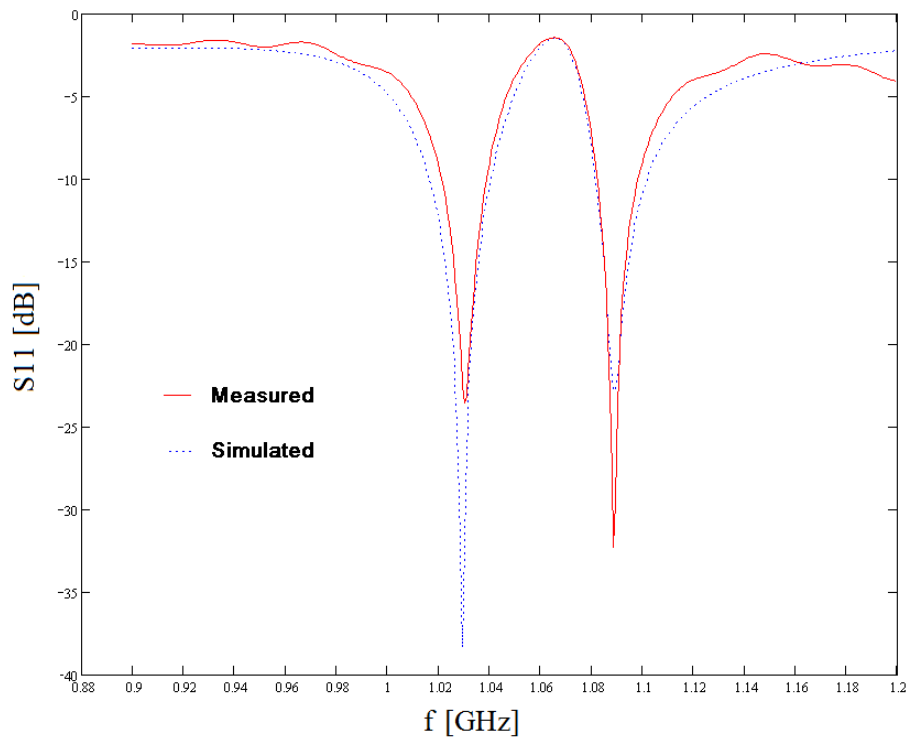


Fig. 2. Measurement and numerical simulation of S_{11} reflection coefficient for final design shown in Fig. 1.

The measured azimuth radiation patterns of the patch radiating element with multilayers of beam-forming networks, shown in Fig. 1, for both operational frequencies of 1.03 GHz and

1.09 GHz are shown in Fig. 3. Fig. 4 shows the measured elevation radiation patterns of the patch radiating element with multilayers of beam-forming networks for operational frequencies of 1.03 GHz and 1.09 GHz. It could be noted that the SSR antenna would be tilted up by 10 degrees. It is well known that an agreement of numerical simulations and measurements of radiation patterns for electrically small antennas is not very good, and therefore the comparisons are not shown.

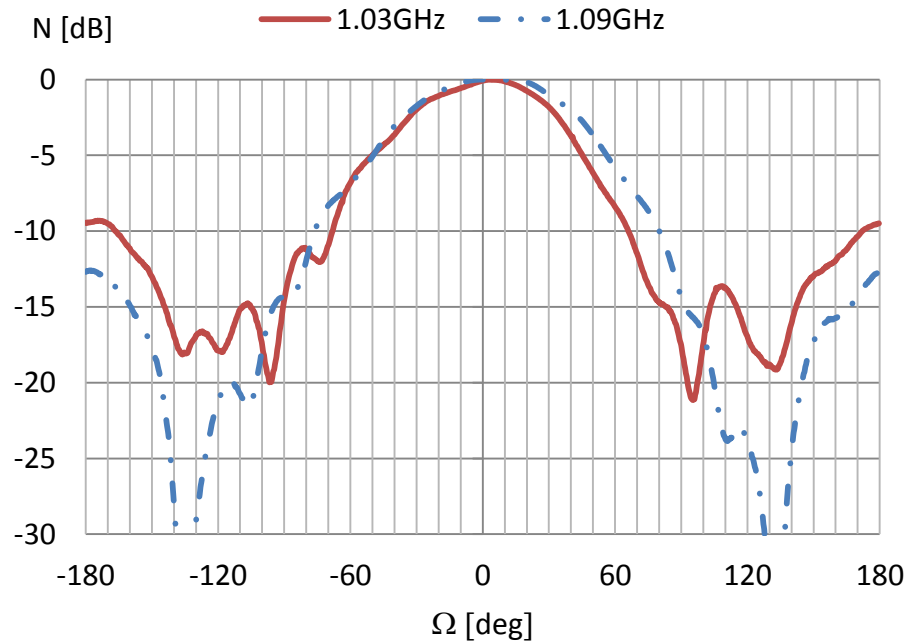


Fig. 3. Measured azimuth radiation patterns of the patch radiating element with multilayers of beam-forming networks shown in Fig. 1.

3. Array Synthesis

The radiation characteristics of an array are given by the pattern multiplication principle i.e. they are equal to the antenna element factor multiplied by the array factor.

According to system requirements, vertical pattern shape is a modified cosecant pattern. The number of elements should be $N = 8$ and they are 180 mm spaced apart. Various synthesis methods have been developed such as [1], [2], [4], [5], [6] and [7]. The well-known Woodward–Lawson method can be easily realized. Moreover, the synthesized pattern exactly equals the desired pattern at the sample points due to the orthogonality of the component beams, resulting pattern can be easily modified and the tolerance requirements could be lower. The SSR elevation pattern for $f = 1.06$ GHz is shown in Fig. 5. Modified cosecant pattern (in fact that is the array

factor) is given by solid line and the cosecant pattern with maximum for 3^0 by crosses. The resulting pattern is specified by system requirements considering the element factor of patch antenna, i.e. the values of array factor should be higher than demanded values.

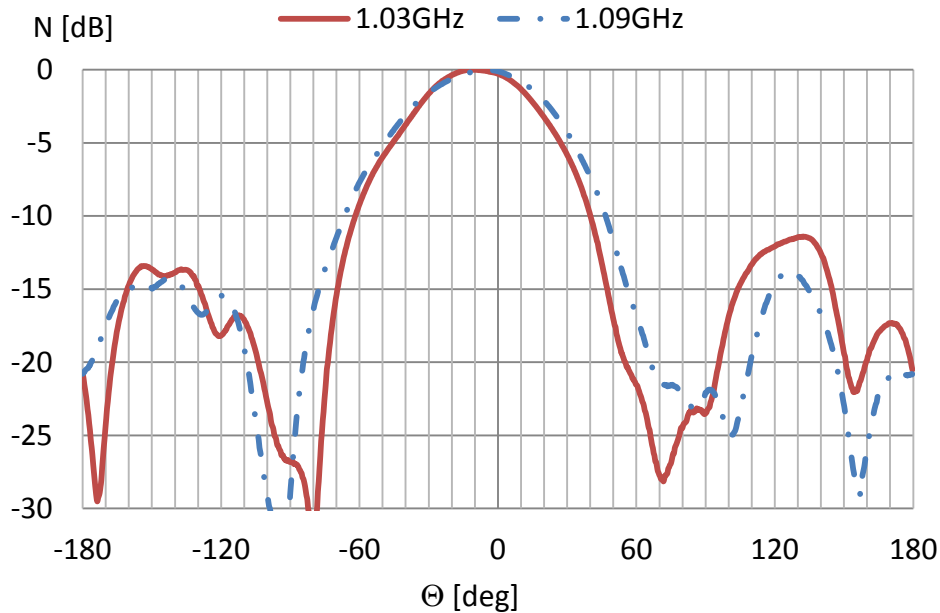


Fig. 4. Measured elevation radiation pattern of the patch radiating element with multilayers of beam-forming networks shown in Fig. 1.

The design of azimuth pattern is rather more complicated as sum, difference and SLS beams should be created. The Taylor distribution [1], [5], [6] and [7] with $\bar{n} = 6$ and 40 dB maximum sidelobes has been considered for Σ beam, which is formed by 27 elements with spacing of 198 mm. After several numerical simulations, it has been found that it is possible to slightly modify the Taylor distribution considering Σ , Δ and SLS beams and use the same distribution for all elements except 3 elements (for n of -1, 0 and 1) in the middle. The considered modification has acceptable low sidelobes and relatively high efficiency for Σ , Δ and SLS beams. In fact, for the given design sidelobe level, the Taylor distribution provides the narrowest beamwidth, i.e. the maximum directivity. The given modification increases slightly the sidelobe levels.

Similarly, the amplitudes for Δ and SLS beam should be modified as is shown in Fig. 6. That allows creating the Σ , Δ and SLS beams, which are not optimal but could be accepted from system point of view. An auxiliary “backfill” antenna is added to cover backlobe radiation. The array factors for the Σ , Δ and SLS beams shown in Fig. 7 considering the directivities of

individual beams and the backfill antenna for $f=1.06$ GHz. The SLS beam level is approximately by 20 dB higher than Σ beam sidelobe level. That is enough for SLS function. Similarly, the SLS beam is by 28.5 dB lower for $\omega = 0^\circ$ and fulfill requirements. It is clear that the proposed solution is a reasonable compromise from the system viewpoint. That allows the utilization of a simple feed network for Σ , Δ and SSL beams, shown in Fig. 8 avoiding rather complicated feed network producing an independently optimized Δ illumination.

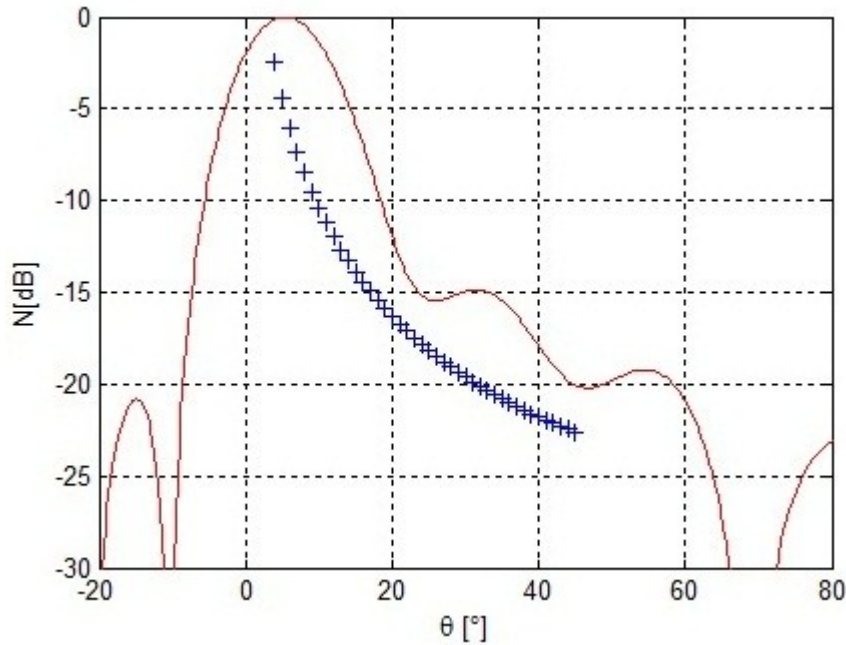


Fig. 5. SSR elevation pattern for $f= 1.06$ GHz. The modified cosecant pattern (array factor) is shown by solid line and the cosecant pattern by crosses.

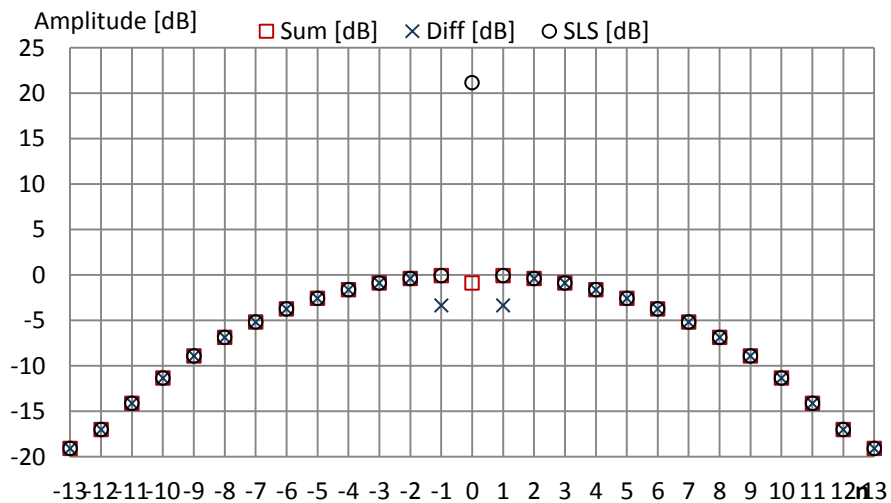


Fig. 6. Element amplitudes of Σ , Δ and SSL beams.

It is well known that antenna patterns are not only given by array factor but the element factor should be counted. That would diminish the level not only for elevation pattern but slightly for azimuth pattern. It is clear that the structure shown in Fig. 1 is not exactly the same as the structure of the whole antenna. Therefore, the element pattern could be different from radiation patterns shown in Fig. 3 and 4. Moreover the tolerances due to element positions, amplitudes and phases will affect the antenna characteristics.

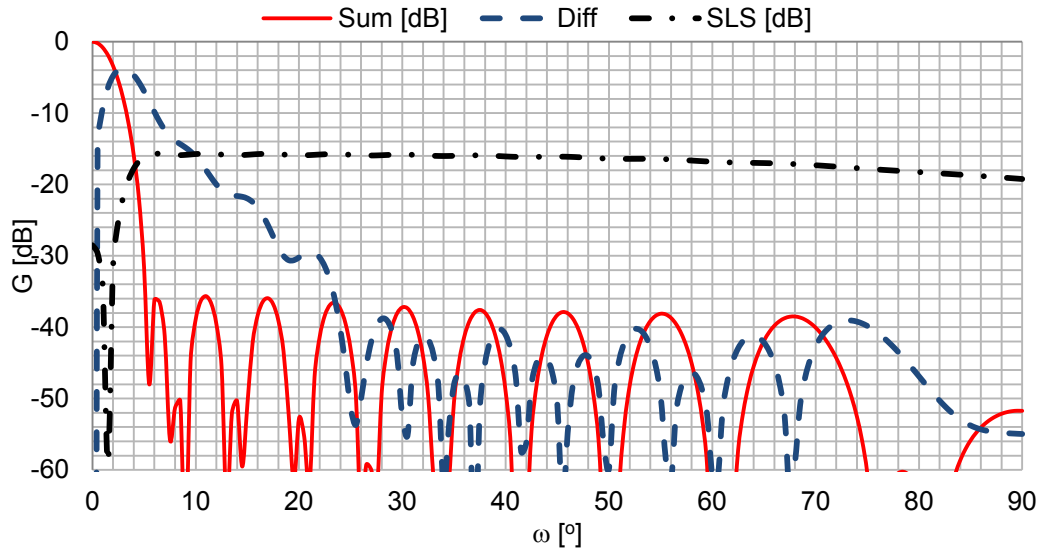


Fig. 7. Azimuth array factors for $f = 1.06$ GHz and Σ , Δ and SLS beams.

4. Coupler design

The feed network for Σ , Δ and SSL (with backfill antenna) beams with branch-line couplers and Wilkinson power divider [8], [9] is shown in Fig. 8. The horizontal feed network for n of 2 to 13 with branch-line couplers is depicted in Fig. 9. The same solution is used for n of -2 to -13. The vertical feed network consists of 7 branch line couplers (see Fig. 10) of different power divisions connected by striplines, providing the appropriate phase and amplitude distribution. The A, ... and H ports are connected to the patch antenna elements.

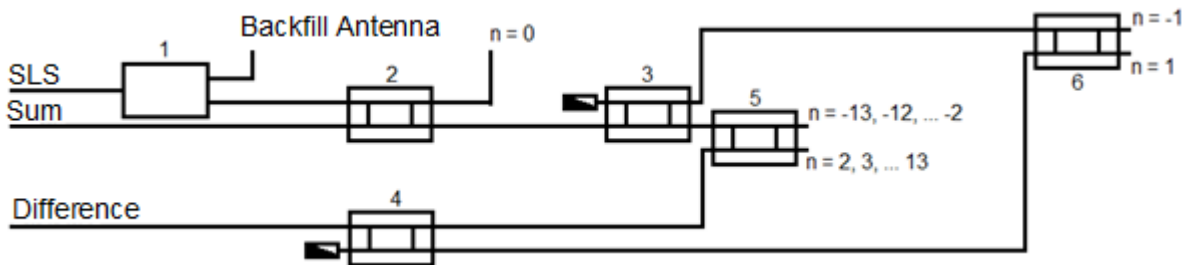


Fig. 8. Horizontal feed network. 1 – Wilkinson Power Divider of 3 dB, 2 to 6 – Branch-Line Couplers.

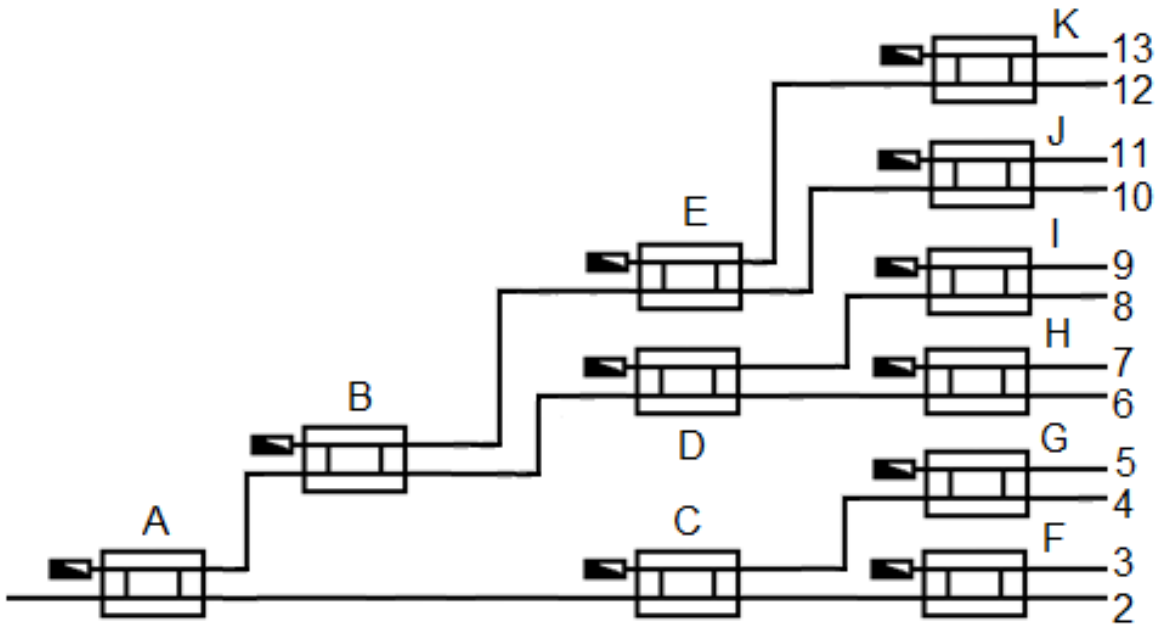


Fig. 9. Horizontal feed network for n of 2 to 13 with Branch-Line Couplers.

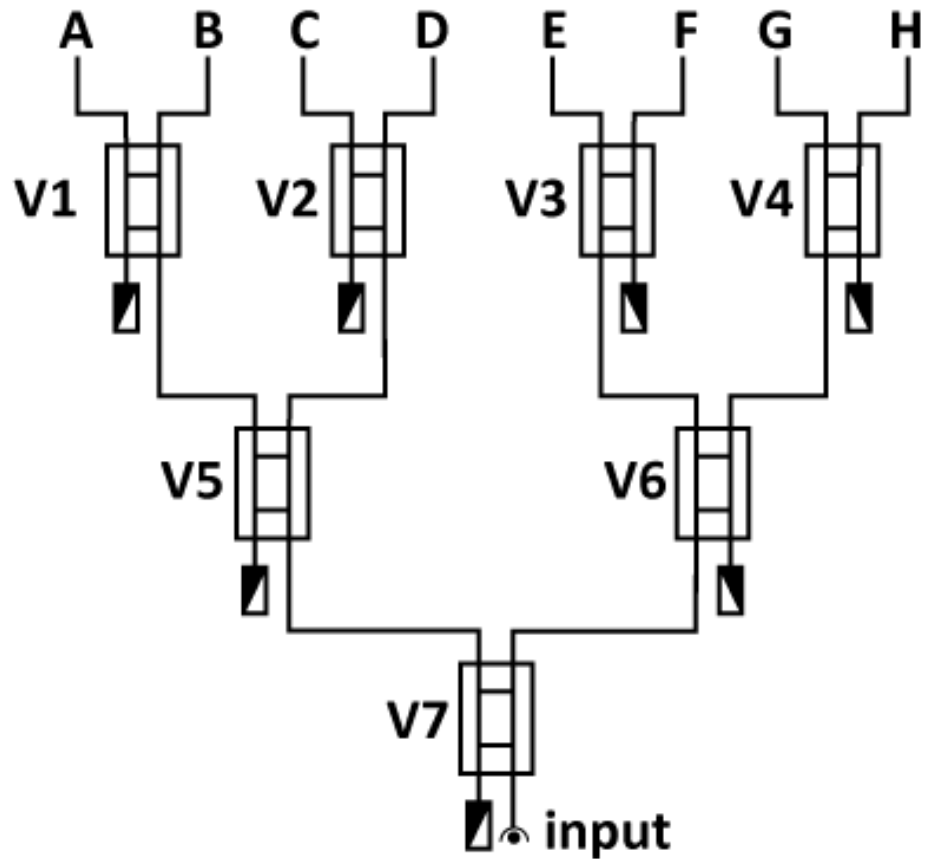


Fig. 10. The vertical feed network. The A to H ports are connected to the antenna elements.

The utilization of suspended stripline techniques brings some advantages [1], [7] and [9]. Using multilayer techniques, one can have layers with patch radiating elements and layers with beam-forming networks. The use of plated-through holes and pins to make RF connections can eliminate cables and connectors. That allows creating very compact design as is shown in Fig. 11 for the vertical feed network. In the first layer the V1 to V4 dividers are placed, where A to H outputs are directly connected to eight antenna elements. The second layer contains the rest three dividers and the feed network input port. Thanks to the proposed modifications the vertical feeder is only 85 mm in depth.

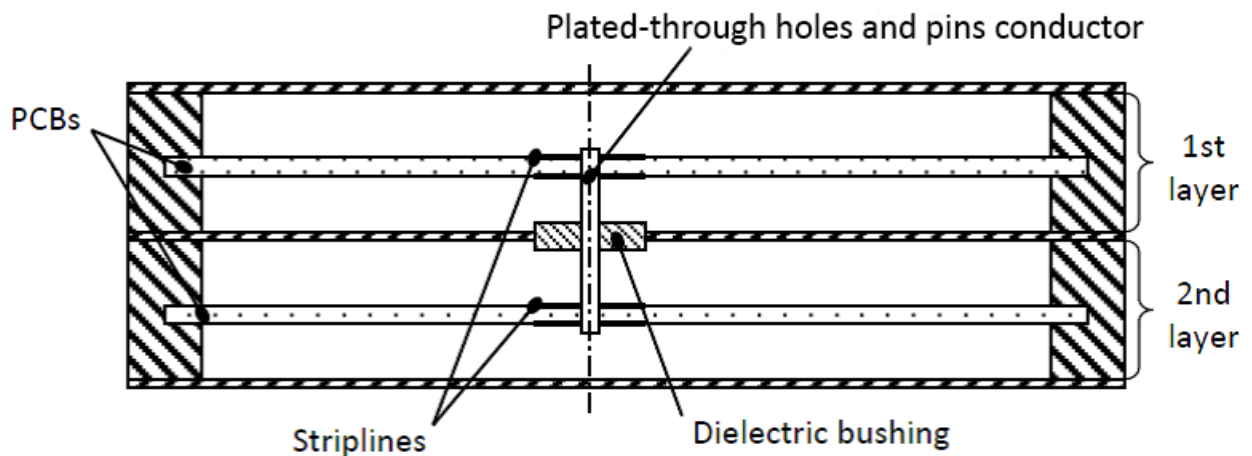


Fig. 11. The layered design of the vertical feed network.

5. Conclusions

The paper depicts the SSR array antenna. That is considered for the system combining the SSR and the primary surveillance radar antennas. Patch array elements are described along with full-wave numerical simulations and measurements of S_{11} , and azimuth and elevation patterns for operational frequencies of 1.03 GHz and 1.09 GHz.

The synthesis for the SSR array is illustrated considering both elevation and azimuth patterns for Σ , Δ and SLS beams. Suspended stripline couplers for the SSR array are briefly described. The utilization of multilayer techniques allows connection of layers with patch radiating elements and layers with beam-forming networks.

6. References

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