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Davor Bonefačić, Juraj Bartolić

E- and H-Plane Coupled Power Combining Arrays of Active Patches with Line Transformer and Transistor Oscillator

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Original scientific paper

A patch antenna integrated with a transistor oscillator and a line impedance transformer has been used as a building element for two-element power combining arrays. Arrays coupled in E and H planes have been theoretically and experimentally investigated. The inter-element distance in the arrays has been optimized to obtain in-phase operation and mutual injection locking. High EIRP and excellent power combining efficiency are measured. The measured spectra are clean and stable. Electronic beam scanning is demonstrated. The co-polarization and cross-polarization radiation patterns are measured for the case of broadside radiation and scanned positions of the main beam. The cross-polarization levels are low.

Key words: antenna, active antenna, microstrip antenna, antenna array, spatial power combining, injection locking

1 INTRODUCTION

Active integrated antennas and arrays find their applications in communications [1] and radar systems [2]. Besides fabrication simplicity and low manufacturing costs, the main advantages of active integrated antenna arrays are the possibility of free space power combining [3–5] and beam scanning without phase shifters [6, 7]. By combining power from multiple sources in free space the losses in combining circuits are avoided. However, all array elements have to be mutually injection locked. Injection locking is achieved through mutual coupling between the array elements. The coupling can be weak (mainly radiative [3, 4]) or strong (e.g. by using coupling lines [8, 9] or integrating oscillators in spatial grids [10]).

This paper demonstrates the application of a compact patch antenna integrated with a transistor oscillator for power combining arrays coupled in E and H planes.

2 PATCH ANTENNA WITH INTEGRATED TRANSISTOR OSCILLATOR

The patch antenna with a line impedance transformer and a transistor oscillator was introduced in [11]. The IE3D electromagnetic simulator from *Zeland Software, Inc*. was used to calculate and optimize the patch dimensions. The rectangular patch was designed for operation in TM_{01} mode at the frequency of 2.3 GHz. The substrate had the height of 1.576 mm, relative dielectric constant 2.55 and the loss tangent of 0.0019. The patch dimensions were 42.3 mm × 34.7 mm. The oscillator circuit and the impedance matching network were placed inside a 10 mm × 25 mm rectangular opening, which has been made symmetrically in the patch. The opening must be large enough for placing the transistor and the impedance matching network, but also it should disturb the current distribution on the patch as little as possible.

The patch is excited at its line of symmetry on one of the opening edges. The relatively high impedance at the center of the opening edge has to be transformed to lower impedance that satisfies the conditions for starting of the oscillations [3]. The suitable impedance transformation has been achieved with a 5 mm × 13.7 mm microstrip line.

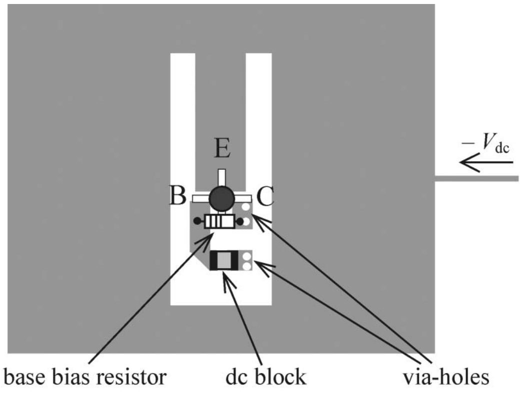

Fig. 1 Active antenna layout

The Hewlett-Packard AT-41485 NPN bipolar transistor in common collector configuration was used as active device for the oscillator. An inductive short-circuited stub for destabilization was connected to the transistor base, while the emitter was the output and it was connected to the line impedance transformer. The dc bias was realized by negative dc voltage connected by a high impedance microstrip line to the center of the patch non-radiating edge. A resistor from the collector to the base provided the base dc biasing. The active patch layout is shown in Figure 1.

3 TWO-ELEMENT ARRAY COUPLED IN E-PLANE

Two active patches, described in the former section, were integrated in an array in E-plane (Figure 2). To obtain power combining, the two spatial oscillators have to be mutually injection locked. In the considered case, mutual injection locking was obtained predominantly by radiation coupling. The coupling strength and phase are determined in terms of the inter-element distance. To facilitate the adjustment of the operating frequencies of the array elements it is most convenient that all elements operate at the same frequency. Usually, it is desirable to obtain maximum power combining in the direction perpendicular to the plane of the array. With all elements operating at the same frequency, this is obtained by adjusting the inter-element distance for the coupling coefficient phase of 0 . Also, the analysis and stability considerations in [7] showed that the coupling phase around 0 gives the best results for weakly coupled spatial power combining arrays.

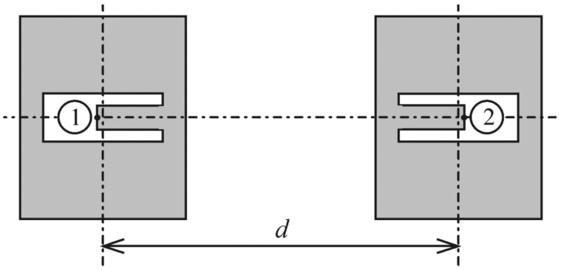

Fig. 2 Active array coupled in E-plane

The array elements were simultaneously excited at ports 1 and 2 (Figure 2). The array element orientation introduces an additional phase shift of 180 , and this has to be compensated by the coupling coefficient phase of 180 .

The inter-element distance and with it the coupling coefficient phase have been optimized by the IE3D electromagnetic simulator package. The desired coupling coefficient phase was obtained for $d = 0.72\ \lambda_0$, where λ_0 denotes the free space wavelength. The computed magnitude and phase of the coupling coefficient are shown in Figure 3. It can be seen that the desired phase of 180 is achieved at the operating frequency of 2.3 GHz. The magnitude of the coupling coefficient at 2.3 GHz is about –39 dB, which confirms that the coupling is weak.

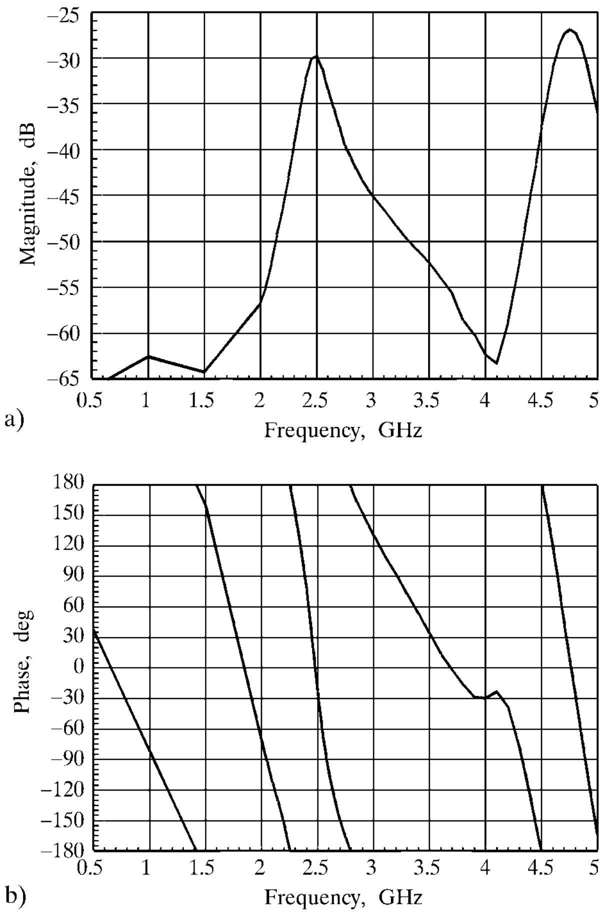

Fig. 3 Magnitude (a) and phase (b) of the coupling coefficient for the active array coupled in E-plane, $d = 0.72\ \lambda_0$

This array showed maximal EIRP of 18.7 dBm and a power combining efficiency of 105 %. A combining efficiency larger than 100 % can be explained by better impedance matching between the oscillator and the patch antenna obtained in the array due to the interaction between the array elements. By changing the bias voltage of one of the array elements a beam scanning of ±17 symmetrically around broadside has been obtained.

Co-polarization and cross-polarization radiation patterns have been measured for broadside radiation and for both maximal obtainable scanned positions of the main beam. The cross-polarization levels for broadside radiation as well as for both scanned beam positions are bellow –20 dB for all angles (Figure 4).

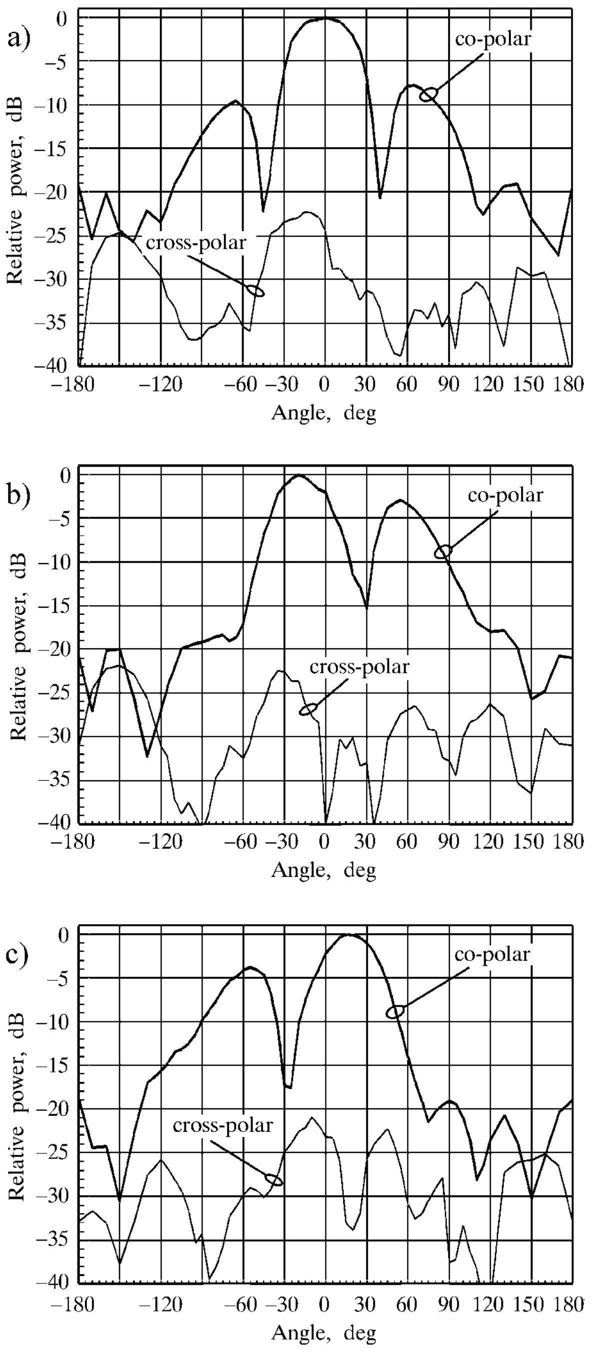

Fig. 4 Measured co-polarization (thick line) and cross-polarization (thin line) radiation patterns for E-plane array; broadside (a); left scan (b); right scan (c)

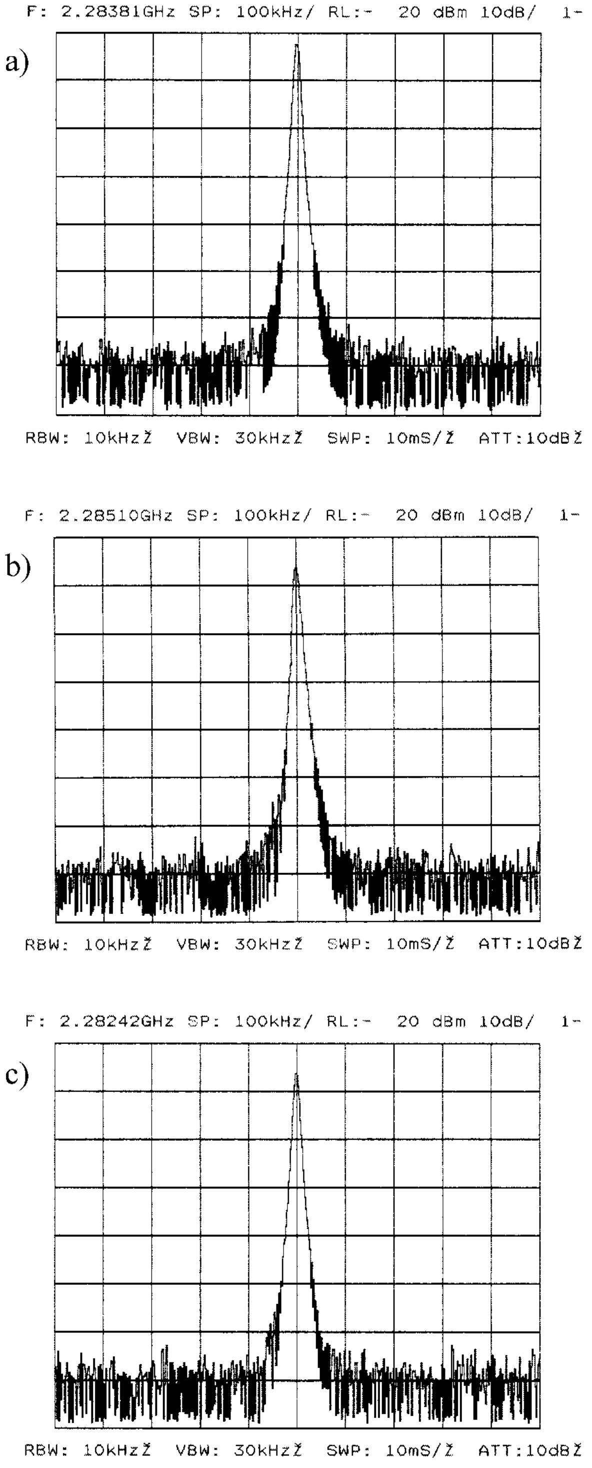

Fig. 5 Measured spectra for the active array coupled in E-plane for broadside radiation (a); left scan (b); right scan (c)

The measured spectrum of this array was clean and stable. The spectra for the cases of broadside radiation and for both scanned positions of the main beam are shown in Figure 5. A slight increase of the noise in the spectrum was observed in the two scanned positions of the main beam (Figures 5 b and 5 c). The increase of the noise in the scanned positions is due to the operation near the end of the injection locking range.

4 TWO-ELEMENT ARRAY COUPLED IN H-PLANE

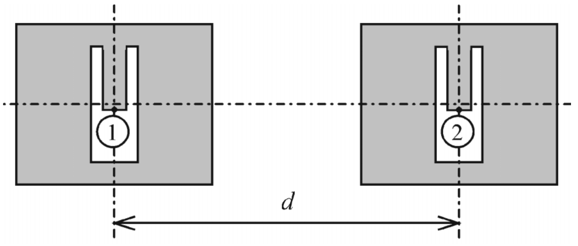

Fig. 6 Active array coupled in H-plane

The array configuration is shown in Figure 6. The inter-element distance has been optimized to obtain the coupling coefficient phase of 0 between the ports 1 and 2 (Figure 6). The desired phase of 0 at the operating frequency of 2.3 GHz was achieved for the inter-element distance of $d = 0.85\ \lambda_0$ (Figure 7.b). At the same frequency, the coupling coefficient magnitude was around –45 dB. The calculated magnitude and phase of the coupling coefficient for the inter-element distance of $d = 0.85\ \lambda_0$ are shown in Figure 7.

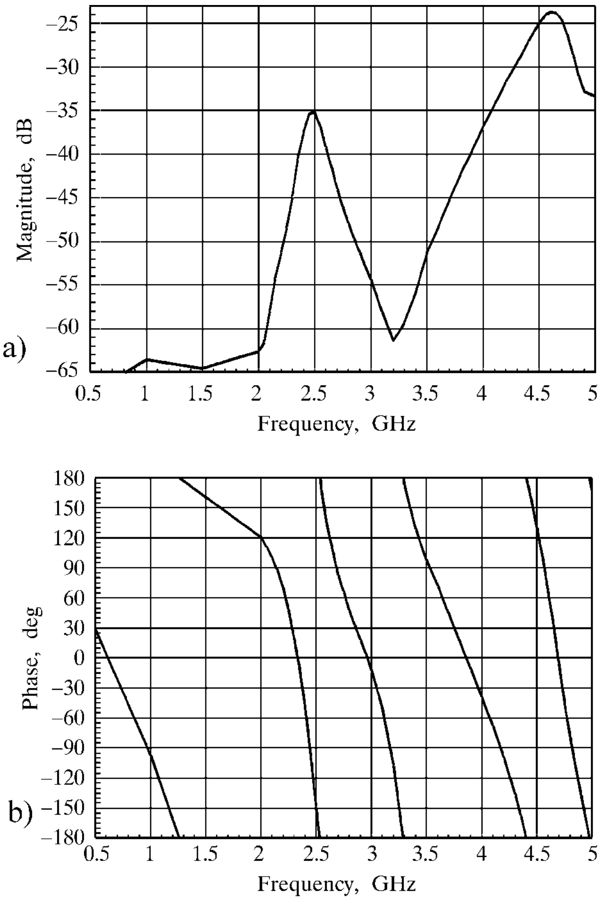

Fig. 7 Magnitude (a) and phase (b) of the coupling coefficient for the active array coupled in H-plane, $d = 0.85\ \lambda_0$

This array showed maximal EIRP of 18.9 dBm and a power combining efficiency of 97 %. Again, beam scanning of ±11 has been obtained by changing the dc bias voltage of one of the array elements.

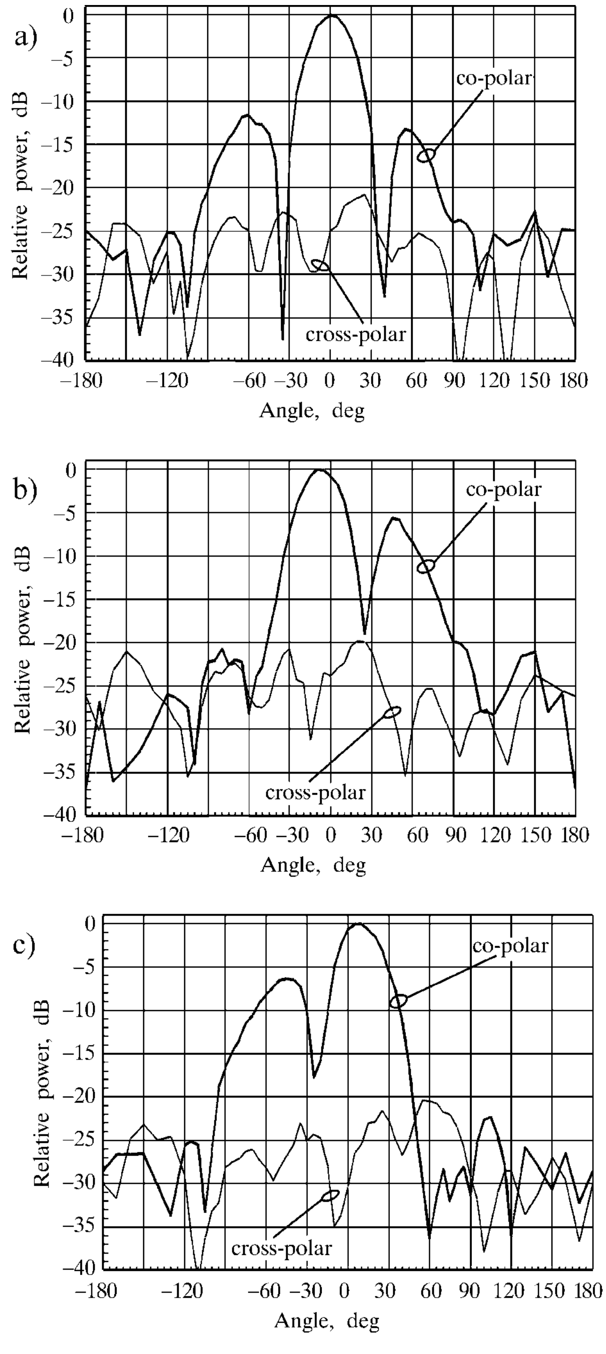

Fig. 8 Measured co-polarization (thick line) and cross-polarization (thin line) radiation patterns for H-plane array; broadside (a); left scan (b); right scan (c)

The measured co-polarization and cross-polarization radiation patterns for broadside radiation and for both scanned positions of the main beam are shown in Figure 8. The cross-polarization levels are bellow –19 dB for all three cases and for all angles.

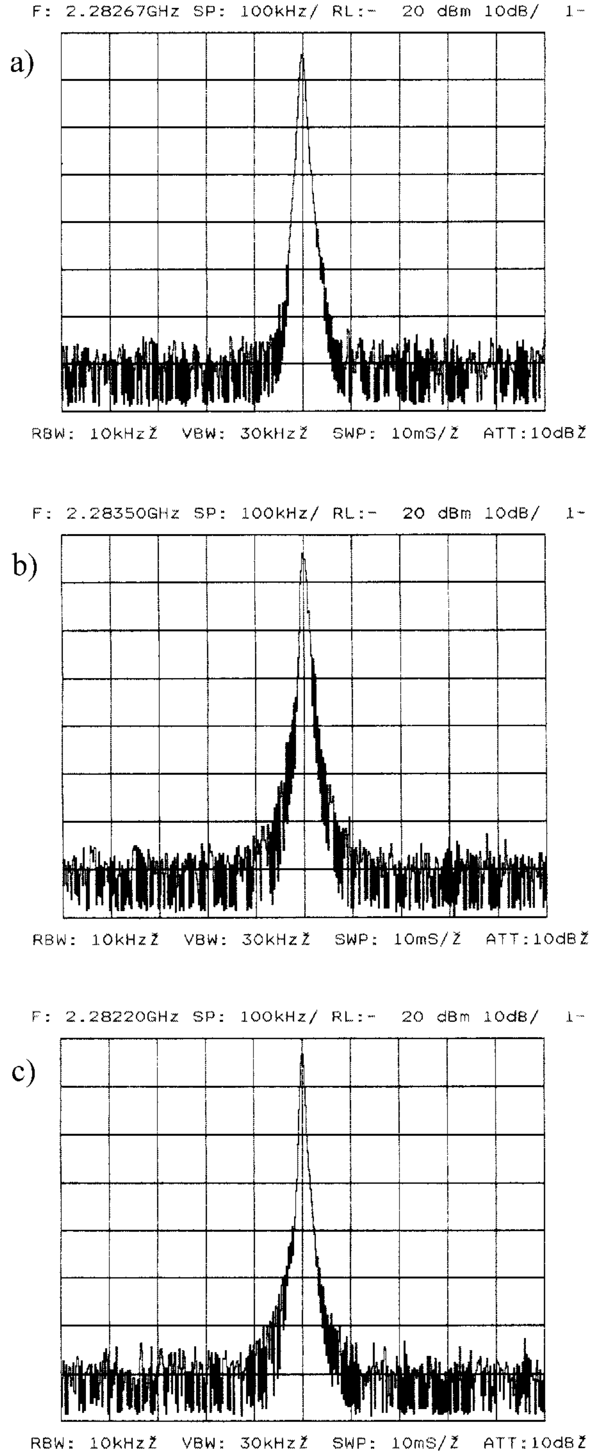

Fig. 9 Measured spectrum for the active array coupled in H-plane for broadside radiation (a); left scan (b); right scan (c)

For both arrays, the measured beam scanning ranges were smaller than the theoretical maximum for given inter-element distance and maximal inter-element phase shift of ±90 (determined by the injection locking condition), because the operation near the edge of the locking bandwidth is unstable. Furthermore, the noise in the spectrum increases by approaching the edge of the locking range. The measured spectra for the array coupled in H-plane for the cases of broadside radiation and for both scanned positions of the main beam are shown in Figure 9.

5 CONCLUSION

A self-oscillating antenna built by integrating an oscillator with bipolar transistor and a line impedance transformer in a rectangular opening inside a rectangular patch has been used as a building element for two power combining active arrays. The IE3D electromagnetic simulator package has been used to optimize the distance between the array elements in order to obtain the desired phase of the coupling coefficient for in-phase operation and mutual injection locking.

In the first array two active antennas were coupled in E plane. Mutual injection locking was mainly achieved by radiative coupling. A beam scanning of ±17 around broadside has been obtained by changing the bias voltage of one active patch. The cross-polarization levels were bellow –20 dB for all angles and positions of the main beam. The active array coupled in E plane has shown a power combining efficiency of 105 %.

In the second array the two active antennas were coupled in H plane. A symmetrical beam scanning of ±11 around broadside has been obtained with cross-polarization levels bellow –19 dB for all angles. For this case a power combining efficiency of 97 % has been achieved.

In both cases stable operation has been obtained for all scanned positions of the main beam. The measured spectra were clean. A slight increase of the noise in the spectrum, measured in the cases of scanned beam positions, was observed.

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Nizovi aktivnih antena s transformatorom impedancije i tranzistorskim oscilatorom spregnuti u ravninama E i H. Mikrotrakasta *patch* antena unutar koje je ugrađen tranzistorski oscilator i linijski transformator impedancije osnovni je element antenskih nizova za prostorno slaganje snage koji su prikazani u ovom radu. Projektirani su i pokusima ispitani antenski nizovi od dva elementa. Elementi su jednom spregnuti u ravnini E, a drugi puta u ravnini H. Udaljenost između elemenata antenskih nizova je optimizirana tako da bi se postigao željeni koeficijent sprege i međusobna sinkronizacija. Mjerenjima je utvrđena visoka razina zračene snage i iznimno dobra djelotvornost prostornog slaganja snage. Pokusima je potvrđen stabilan rad oba antenska niza i izmjeren je čist spektar. Prikazana je i mogućnost elektroničkog zakretanja glavnog snopa zračenja. Izmjereni su dijagrami zračenja osnovne i križne polarizacije za oba niza u slučaju zračenja okomito na os niza kao i u oba zakrenuta položaja glavnog snopa zračenja. Mjerenja su pokazala niske razine križne polarizacije.

Ključne riječi: antena, aktivna antena, mikrotrakasta antena, antenski niz, prostorno slaganje snage, sinkronizacija

AUTHORS' ADDRESSES:

Doc. dr. sc. Davor Bonefačić, dipl. ing.
Prof. dr. sc. Juraj Bartolić, dipl. ing.
University of Zagreb
Faculty of Electrical Engineering and Computing
Department of Radiocommunications and Microwave Engineering
Unska 3, HR-10000 Zagreb, CROATIA
e-mail: davor.bonefacic@fer.hr
e-mail: juraj.bartolic@fer.hr

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