Active Log-Periodic Antennas for Spatial and Quasi-Optical Microwave Power Combining

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Abstract- **Microstrip log-periodic antennas on the dielectric substrates, integrated with Gunn diodes and field-effect transistors, were investigated and employed as microwave and millimeter wave power sources. Spatial power combining is experimentally studied with array of such oscillators in the case of mutual synchronization or synchronization with external signal. The opportunity for considerable increasing of the oscillation efficiency is shown and conditions for the radiation pattern formation are defined.**

I. INTRODUCTION

Microwave power combining is important in application to energy transportation systems and the way to compensate the well-known decreasing of solid-state devices output power in the millimeter-wave frequency range[1,2]. Power sources, designed as an antenna, integrated with active device (active antennas), are considered as the best candidates for the spatial power combiners due to the fact, that they are free of losses in the feed lines, compact and low cost [3]. Mostly dipole or patch antennas are used in such constructions, in particular, a butterfly antenna on the dielectric plate with metal shield at the back side [4]. In this work we have used the log-periodic antenna due to wide-band operation ability and proper quality factor [5] with Gunn diodes or field-effect transistors as active elements.

II. EXPERIMENTAL

The configuration of active antenna (AA) is shown at fig.1. In the case of FET imbedding "source" terminal is grounded and corresponding bias voltages are applied to the patches. Dielectric plate (ε=3,5), covered with copper at the back side, was used as a substrate for the log-periodic antenna.

Log-periodic antenna in fact is a combination of resonating elements with resonant frequencies corresponding to the teeth length *l*. The dielectric thickness plays a considerable role in the oscillation efficiency. Maximum power is achieved at $d \approx \lambda_d/4$ (λ_d is a wavelength in the dielectric substrate). Variation of dielectric thickness *d* results in oscillations at the frequencies, corresponding to more high resonance frequencies or transfer to the multi-frequency operation.

III. COMPUTER MODELING

To verify the radiating properties of the single log-periodic antenna the computer modeling was performed. Geometry presented on fig. 1 was modeled using 3D-TLM technique. We have evaluated the antenna with the largest tooth designed to have main resonance frequency of 10 GHz. The discrete voltage source with 0.1V amplitude was used instead of the FET or Gunn diode to obtain the radiated field. The main goal was to examine radiating properties at thin dielectrics due to a quite easy real manufacturing process.

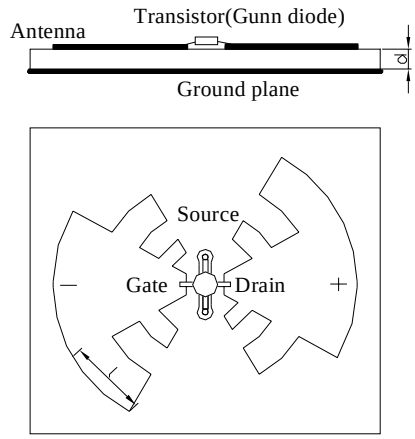

Figure 1. Active log-periodic antenna:
a) cross-section, b) front view (with FET).

During the experiments it was found that the resonant frequencies slightly vary with the dielectric thickness change from 0 to $\lambda d/4$. At the same time radiated power measured at 10 GHz increases with the dielectric thickness growth from 0 to $\lambda d/4$ (fig. 2).

Radiation patterns of the explored antennas have directivity about 7 dBi and the main lobe is oriented at normal to the antenna' s plane. The pattern in E and H planes in the case of $d \approx \lambda d/4$ is shown on fig. 3.

Frequency antenna response in the case of the maximum radiated power measured at 10 GHz ($d \approx \lambda d/4$) has two more resonant frequencies in the range from 7.5 to 22.5 GHz corresponding to the second and third antenna tooth respectively (fig. 4).

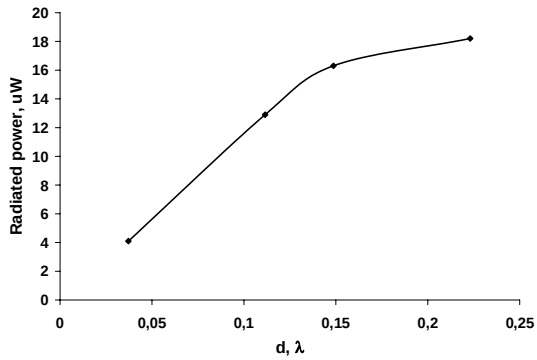

Figure 2. Impact of the dielectric thickness.

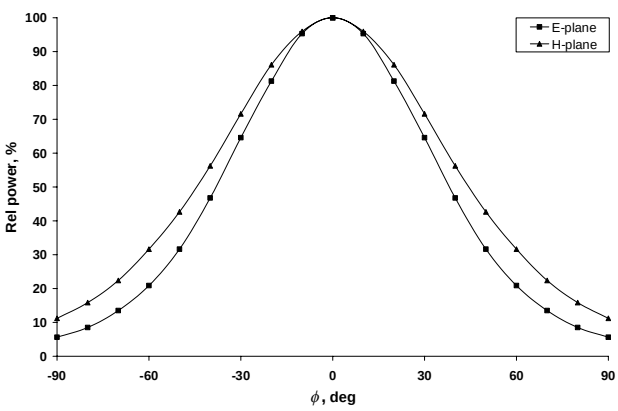

Figure 3. Radiation pattern.

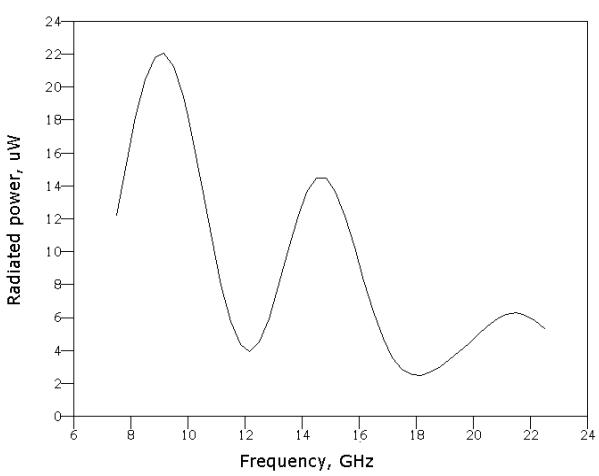

Figure 4. Frequency response.

The power of the secondary peaks also increases with the dielectric thickness growth from 0 to λd/4.

IV. 4. Experimental results and discussion

The oscillation frequency of AA with Gunn diode corresponds to the transit-time mode of operation and is not considerably dependent on the dielectric substrate thickness. However, only narrow bandwidth radiation is possible and efficiency is small [6].More efficient operation was achieved with the field-effect transistor. The oscillation frequency depends both on the sizes of resonating teeth and thickness of the dielectric substrate d. In the basic construction (fig.1) oscillation frequency corresponds to the main tooth size (l≈ λ d/4).

Placing the couple of active antennas at the substrate forms the array of mutually synchronized oscillators (fig.5).

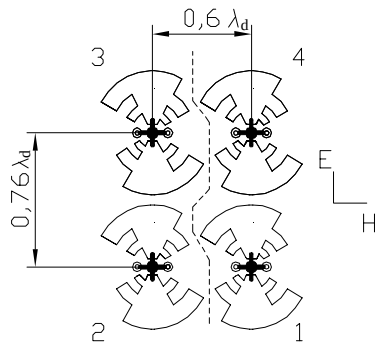

Figure 5. Active 2x2 antenna array.

The simultaneous operation of the array elements was resulted in the single frequency due to the mutual synchronization of the oscillators (fig.6).

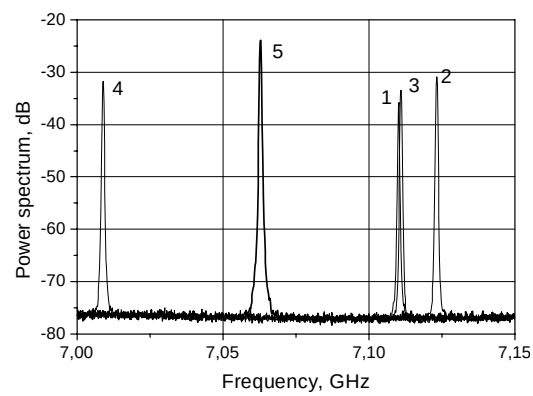

Figure 6. Power spectrum of AA for the case of selected (1-4) and joint (5) operation.

Probably, the surface waves, exited in the dielectric substrate, played a main role in this interaction. It is confirmed with computer simulation of the electromagnetic field distribution around the antenna using the 3D-TLM model and far field transformation. Separation of the antennas as it is shown at the fig.2 with dashed curve, eliminates the effect of synchronization.

Effect of power combining and narrowing of the radiation pattern was achieved for two antennas (2 and 3 at fig.5). Results are shown at fig.7 and in the table 1.

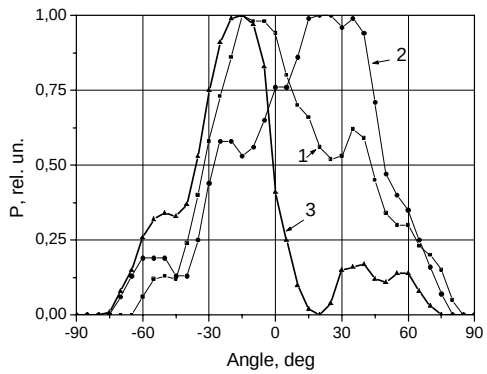

Figure 7. E-plane radiation pattern of AA 2 and 3 in the case of independent (1, 2) and joint (3) operation.

TABLE I

Radiating antennas	1	2	3	4	1+2	2+3
P_{out}, mW	1.4	3.7	3.3	4.7	3.3	8.4

The fact, that resulting power level is more than the sum of output power levels for these antennas in the case of separate operation, can be explained with increasing of the efficiency due to the mutual enforcement of the oscillators. Irradiation of the AA with external power source shows an alternative opportunity for increasing of the oscillation efficiency (fig.8).

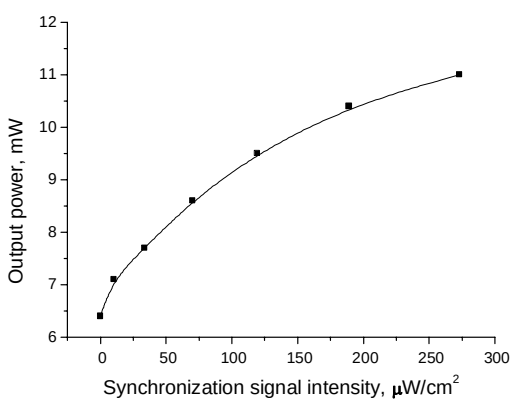

Figure 8. Effect of the AA synchronization with external irradiation.

V. CONCLUSION

Log-periodic antenna, integrated with FET or Gunn diode, is a compact microwave and millimeter wave power source, prospective candidate for spatial and quasi-optical power combining. Before such antennas were effectively used in the arrays only with detectors, not with active devices. Next step should be in the monolithic integration, based on the i-GaAs or other dielectric as the substrate. Possible applications are in the microwave energy transportation and telecommunication systems.

REFERENCES

[1] M.P. DeLisio and R.A. York, "Quasi-Optical and Spatial Power Combining", IEEE Trans. MTT, vol. 50, n. 3, pp. 929-936, 2002.

[2] H. Eisele. "Conventional and Novel Approaches to RF Power Generation with Two-Terminal Devices at Terahertz Frequencies". Tenth IEEE Int. Conf. on Terahertz Electronics, Cambridge, UK, 2002

[3] R.A. York and R.C. Compton, "Quasi-Optical Power Combining Using Mutually Synchronized Oscillator Arrays", IEEE Trans. MTT, vol. 36, n. 6, pp. 1000-1009, 1991.

[4] M. Murata, T. Matsui, M. Tanaka and S. Ohmori, "Active Radiating Butterfly Antenna", *IEEE Antennas and Propagation Society International Symposium Digest*, vol. 4. pp. 2464-2467, 1997.

[5] M.M Gitin, F.W. Wise, G. Arjavalingam, Y. Pastol, R.C. Compton, "Broad-Band Characterisation of Millimeter-Wave Log-Periodic Antennas by Photoconductive Sampling", IEEE Trans. AP, vol. 42, pp.335-339, 1994.

[6] V.E. Lyubchenko, V.D. Kotov, E.O. Yunevich. Active microstrip antenna with a Gunn Diode. Radiophysics and Quantuum Electronics, vol. 46, n. 8, pp.717-721, 2003.