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Complex Effective Dielectric Permittivity of Micromechanically Tunable Microstrip Lines

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Abstract—It is considered an influence of physical-topological parameters of controlled microstrip lines where characteristics modification is achieved by signal electrode movement over the substrate on effective dielectric permittivity and electromagnetic energy loss in the line expressed in form of complex permittivity. There are stated the ways of increase of sensitivity of effective dielectric permittivity modification to signal electrode shift and loss decrease. There are determined ultimate characteristics of tuning and loss. There are represented calculations of transfer factor effective permittivity corresponding to experimental results. These results can be used for development of controlled resonant elements and phase shifters with application of electrically tunable micromovement devices, such as piezo- and electrostrictive actuators or microelectromechanic systems. Due to application of invariant relations of physical-topological parameters represented calculations are suitable for estimation of tuning factors and loss of devices with micromechanical control in a wide range of operating frequency with application of wide range of materials.

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INTRODUCTION

Despite of progress in solid-state components for microwave band operation devices, research and development of mechanically tunable microwave elements is not only actual problem [1] but it also becomes more important with implementation of such promising technologies as micromechanical systems (MEMS) [3] and 3D printing [3]. Controlled microstrip lines (MSL) are applied for creation of tunable microwave devices as phase shifters [4] and filters [5, 6]. These constructions allow to achieve frequency and phase tuning in wide range in case of conservation and sometimes improve of Q-factor which cannot be achieved applying solid-state devices [7–9].

Operation principle of such returnable devices lies in modification of electric path of electromagnetic wave which can be achieved by both modification of geometric dimensions of the devices parts and modification of their effective parameters. In contrast to traditional way of tuning and retuning the last way gives the possibilities for tuning realization with electromechanic method by means of piezodrivers and MEMS.

For example, modification of effective dielectric permittivity ε_{eff}, and, hence, wave propagation constant can be achieved by means movement off dielectric body over a surface of microstrip line or coplanar line [10] or by movement of a dielectric body inside a waveguide [3]. Constructions described in mentioned papers require moment of controlling bodies by units–tens millimeters for realization of required phase shifts. The authors of the current research work over development of such mechanic tuning principles that allow to achieve the required tuning factor in case of controlling body movement by tens micrometers that allows directly applying of fast response piezodrivers.

In general case proposed tunable MSL consists of substrate and metallic electrodes one of them can move over the substrate surface by controlled distance. Such line reconfiguration results in redistribution electromagnetic field of propagated wave between the substrate and created air gap. As a result of such redistribution the wavelength in the line is changed.

Micromechanic retuning can be realized with many ways. The great tuning range is achieved in devices where the signal electrode moves in case of the last equal conditions [6] (Fig. 1).

REFERENCES

1. S. Kurudere, V. B. Erturk, "Novel microstrip fed mechanically tunable combline cavity filter," *IEEE Microwave and Wireless Components Lett.* **23**, No. 11, 578 (Nov. 2013). DOI: 10.1109/LMWC.2013.2281432.
2. S. Fouladi, F. Huang, W. D. Yan, R. R. Mansour, "High-Q narrowband tunable combline bandpass filters using MEMS capacitor banks and piezomotors," *IEEE Trans. Microwave Theory Tech.* **61**, No. 1, 393 (Jan. 2013). DOI: 10.1109/TMTT.2012.2226601.
3. Brendan T. W. Gillatt, Mario D'Auria, William J. Otter, N. M. Ridler, S. Lucyszyn, "3-D printed variable phase shifter," *IEEE Microwave and Wireless Components Lett.* **26**, No. 10, 822 (2016). DOI: 10.1109/LMWC.2016.2604879.
4. P. Romano, O. Araromi, S. Rosset, J. Perruisseau-Carrier, H. Shea, J. R. Mosig, Juan Ramon, "Low-loss millimeter-wave phase shifters based on mechanical reconfiguration," *Proc. of Progress In Electromagnetics Research Symp.*, PIERS, 6-9 Jul. 2015, Prague (Prague, 2015). URI: https://infoscience.epfl.ch/record/210386.
5. D. Bouyge, D. Mardivirin, J. Bonache, Aurelian Crunteanu, Arnaud Pothier, Miguel Duran-Sindreu, Pierre Blondy, Ferran Martin, "Split ring resonators (SRRs) based on micro-electro-mechanical deflectable cantilever-type rings: application to tunable stopband filters," *IEEE Microwave and Wireless Components Lett.* **21**, No. 5, 243 (2011). DOI: 10.1109/LMWC.2011.2124450.
6. Y. Poplavko, Y. Prokopenko, V. Pashkov, V. Molchanov, I. Golubeva, V. Kazmirenko, D. Smigin, "Low loss microwave piezo-tunable devices," *Proc. of 36th European Microwave Conf.*, 10-15 Sept. 2006, Manchester, UK (IEEE, 2006), pp. 657-660. DOI: 10.1109/EUMC.2006.281496.
7. Jia Ni, Jiasheng Hong, "Varactor-tuned microstrip bandpass filters with different passband characteristics," *IET Microwaves*, *Antennas & Propag.* **8**, No. 6, 415 (2014). DOI: 10.1049/iet-map.2013.0474.
8. M. F. Karim, Y.-X. Guo, Z. N. Chen, L. C. Ong, "Miniaturized reconfigurable and switchable filter from UWB to 2.4 GHz WLAN using PIN diodes," *IEEE MTT-S Int. Microwave Symp. Dig.*, 7-12 Jun. 2009, Boston, MA, USA (IEEE, 2009), pp. 509-512. DOI: 10.1109/MWSYM.2009.5165745.
9. Zhang Jin, S. Ortiz, A. Mortazawi, "Design and performance of a new digital phase shifter at X-band," *IEEE Microwave Wireless Components Lett.* **14**, No. 9, 428 (Sept. 2004). DOI: 10.1109/LMWC.2004.832049.
10. T.-Y. Yun, K. Chang, "Analysis and optimization of a phase shifter controlled by a piezoelectric transducer," *IEEE Trans. Microwave Theory Tech.* **50**, No. 1, 105 (2002). DOI: 10.1109/22.981254.
11. I. Golubeva, V. Kazmirenko, P. Sergienko, Y. Prokopenko, "Effective permittivity in tunable microstrip and coplanar lines," *Proc. of XXXII Int. Sci. Conf. on Electronics and Nanotechnology*, ELNANO, 10-12 Apr 2012, Kyiv, Ukraine (Kyiv, 2012), pp. 69-70. URI: http://www.journals.kpi.ua/publications/text/69_70_2012.pdf.
12. Yu. V. Prokopenko, "Controllability range of dielectric inhomogeneity located between the metal planes," *Tehnologiya i Konstruirovanie v Elektronnoi Apparature*, No. 6, 16 (2012). URI: http://www.tkea.com.ua/english/tkea/2012/6_2012/st_04.htm.
13. K. C. Gupta, *Microstrip Lines and Slotlines*, 2nd ed. (Artech House, 1996).
14. P. Yu. Sergienko, V. A. Kazmirenko, A. S. Chernov, Yu. V. Prokopenko, "Q-factor of tuned microstrip resonator," *Radioelectron. Commun. Syst.* **59**, No. 2, 89 (2016). DOI: 10.3103/S0735272716020060.
15. P. Sergienko, I. Golubeva, Y. Prokopenko, "Loss in tunable microstrip lines," *Proc. of IEEE 34th Int. Conf. on Electronics and Nanotechnology*, ELNANO, 15-18 Apr. 2014, Kyiv, Ukraine (IEEE, 2014), pp. 97-100. DOI: 10.1109/ELNANO.2014.6873972.
16. A. I. Akhiezer, I. A. Akhiezer, *Electromagnetism and Electromagnetic Waves* [in Russian] (Vyssh. Shkola, Moscow, 1985).