













**Figure 9.** The absolute error analysis results of ANN-based Sprott 94 S system implemented on FPGA

## 5. Conclusion

In the presented work, nonlinear Sprott 94 S system has been modelled using the approximation of LogSig transfer function on FPGA. The performed modelling of ANN's architecture has been developed using VHDL with IEEE-754-1985 32-bit single precision floating-point arithmetic. The design of ANN-based Sprott 94 S system has been synthesized using Xilinx ISE Design Tools and tested using 3X100 data set. The error analysis results related to obtained tests have been presented. The performed design has been implemented with the Place&Route process for Xilinx VIRTEX-6 family, XC6VHX255T-3FF1923 FPGA chip and chip utilization statistics have been given. The ANN-based Sprott 94 S system having pipeline processing scheme on FPGA can be used with a clock frequency up to 304.534 MHz and ANN-based system has produced 3X3.284 billion outputs in 1 s. As further work, different nonlinear systems can be modelled using FPGA-based ANNs. Thus the performance and error analysis can be performed using obtained results. In future, embedded secure communication applications can be performed using the proposed ANN-based Sprott 94 S system on FPGA.

## References

- [1] H. H. Chiang, K. C. Hsu and I. H. Li (2015). Optimized adaptive motion control through an SoPC implementation for linear induction motor drives. *IEEE/ASME Transactions on Mechatronics*. Vol. 20(1). Pages. 348–360.
- [2] Y. Yue, S. W. Feng, C. S. Guo, X. Yan and R. R. Feng (2015). All-digital thermal distribution measurement on field programmable gate array using ring oscillators. *Microelectronics Reliability*. Vol. 55(2). Pages. 396–401.
- [3] E. Tlelo-Cuautle, V. H. Carbajal-Gomez, P. J. Obeso-Rodelo, J. J. Rangel-Magdaleno and J. C. Nuñez-Perez (2015). FPGA realization of a chaotic communication system applied to image processing. *Nonlinear Dynamics*. Vol. 82(4). Pages. 1879–1892.
- [4] Ö. Polat and T. Yıldırım (2010). FPGA implementation of a general regression neural network: an embedded pattern classification system. *Digital Signal Process*. Vol. 20. Pages. 881–886.
- [5] M. Milanovic, M. Truntic, P. Slibar and D. Dolinar (2007). Reconfigurable digital controller for a buck converter based on FPGA. *Microelectronics Reliability*. Vol. 47(1). Pages. 150–154.
- [6] I. Sahin (2011). A 32-bit floating-point module design for 3D graphic transformations. *Scientific Research Essay*. Vol. 5(20). Pages. 3070–3081.
- [7] J. X. Wu, C. H. Lin, Y. C. Du, P. J. Chen, C. C. Shih and T. Chen (2010). Estimation of arteriovenous fistula stenosis by FPGA based Doppler flow imaging system. 2015 IEEE International Symp. In Ultrasonics (IUS). Pages. 1–4.
- [8] J. Vanhamel, D. Fussen, E. Dekemper, E. Neefs, B. Van-Opstal, D. Pieroux and P. Leroux (2015). RF-driving of acoustic-optical tunable filters; design, realization and qualification of analog and digital modules for ESA. *Microelectronics Reliability*. Vol. 55(9). Pages. 2103–2107.
- [9] M. Alçın, . Pehlivan, and . Koyuncu (2016). Hardware design and implementation of a novel ANN-based chaotic generator in FPGA. *Optik-International Journal for Light and Electron Optics*. Vol. 127(13). 5500-5505.
- [10] M. T. Hagan, H. B. Demuth and M. Beale (2002). *Neural network design*. Thomson Learning Press. ISBN-10: 7111108418.
- [11] I. Koyuncu, A. T. Ozcerit and I. Pehlivan (2014). Implementation of FPGA-based real time novel chaotic oscillator. *Nonlinear Dynamics*. Vol. 77. Pages. 49–59.
- [12] X. Yang, J. Cao and D. W. Ho (2014). Exponential synchronization of discontinuous neural networks with time-varying mixed delays via state feedback and impulsive control. *Cognitive Neurodyn*. Vol. 9. Pages. 113–128.
- [13] J. Fei and H. Ding (2012). Adaptive sliding mode control of dynamic system using RBF neural network. *Nonlinear Dynamics*. Vol. 70. Pages. 1563–1573.
- [14] D. Avci, M. K. Leblebicioglu, M. Poyraz and E. Dogantekin (2014). A new method based on adaptive discrete wavelet entropy energy and neural network classifier (ADWEENN) for recognition of urine cells from microscopic images independent of rotation and scaling. *Journal Medical Systems*. Vol. 38(2). Pages. 1–9.
- [15] S. L. Ho and Y. Shiyou (2012). A fast robust optimization methodology based on polynomial chaos and evolutionary algorithm for inverse problems. *IEEE Transactions on Magnetics*. Vol. 48(2). Pages. 259–262.

- [16] C. J. Lin, H. M. Tsai (2008). FPGA implementation of a wavelet neural network with particle swarm optimization learning, *Math. & Comp. Modell.* Vol. 47. Pages. 982–996.
- [17] O. L. Savkay, V. Tavsanoğlu, M. E. Yalcin and E. Cesur (2015). Computer assisted sperm analysis system designed on a hybrid CPU+ FPGA architecture. 23th IEEE Signal Processing and Communications Applications Conference (SIU). Pages. 1425–1428.
- [18] V. Paukštaitis and A. Dosinas (2009). Pulsed neural networks for image processing. *International Journal of Electronics and Electrical Eng.* Vol. 7. Pages. 15–20.
- [19] H. Papadopoulos and H. Haralambous (2011). Reliable prediction intervals with regression neural networks. *Neural Networks.* Vol. 24. Pages. 842–851.
- [20] M. Kanayama, A. Rohe and L. A. Paassen (2014). Using and improving neural network models for ground settlement prediction. *Geotechnical and Geological Engineering.* Vol. 32. Pages. 687–697.
- [21] S. Haykin (1999). *Neural networks a comprehensive foundation.* Prentice Hall.
- [22] J. C. Sprott (1994). Some simple chaotic flows. *Physical Review E.* Vol. 50(2). Pages. 647–650.
- [23] Ü. Çavuşoğlu, A. Akgül, S. Kaçar, İ. Pehlivan and A. Zengin (2016). A novel chaos-based encryption algorithm over TCP data packet for secure communication. *Security and Communication Networks.* DOI: 10.1002/sec.1414.
- [24] S. Senthilkumar and A. Piah (2012). An improved fuzzy cellular neural network (IFCNN) for an edge detection based on parallel Runge-Kutta (5, 6) approach. *International Journal of Computational Systems Engineering.* Vol. 1(1). Pages. 70–78.
- [25] İ. Sahin and İ. Koyuncu (2011). FPGA çipleri için CORDIC Tabanlı  $\exp(x)$  hesaplama ünitesi tasarımı. *e-Journal of New World Sciences Academy.* Vol. 6(4). Pages. 1565–1572.