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Predicting Noise Power in Gm-C Filters through Machine Learning

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THE AIM

A novel approach for predicting the total noise power in biquad low pass second order Gm-C filter through application of machine learning algorithms to be presented

GM-C FILTERS

- The increased interest to the continuous-time Gm-C filters is connected to their features like:
  - high bandwidth
  - possibilities for parameters tuning in large frequency diapason
  - very low passive sensitivity
- Their successful applications are:
  - in high frequency computers
  - communication systems
  - bio-medical devices

Noise in Gm-C filters

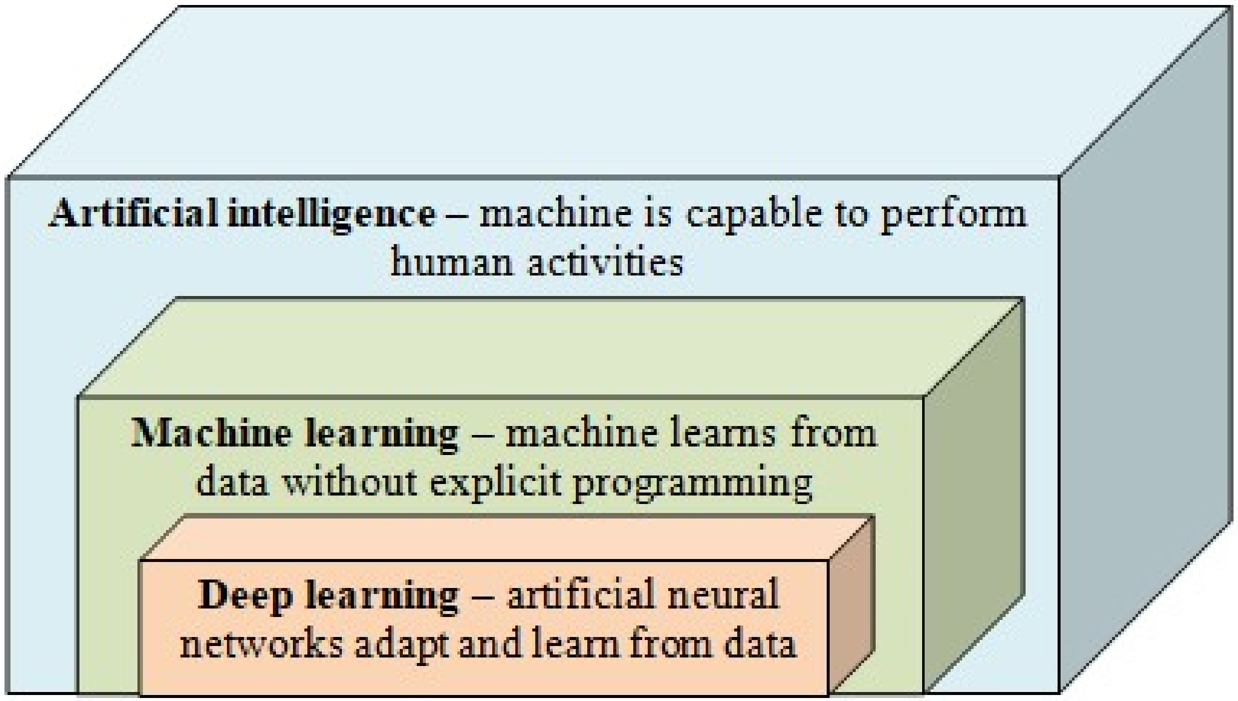
- Noise depends on the design of the transconductor cell and on the Gm-C filters topology
- The research efforts are focused on minimization the noise level in the filters that will lead to the larger dynamic range and higher ratio signal/noise
- The dominant noise in Gm-C filters is thermal noise, but flicker noise is also taken into consideration
- The sources of noise are MOS transistors:
  - thermal noise (white noise) is generated in the channel as consequence of random charge carriers movement
  - flicker noise (or pink noise) is product of random mobile carriers trapping and detrapping in the channel and in the gate oxide

NOISE MODELING

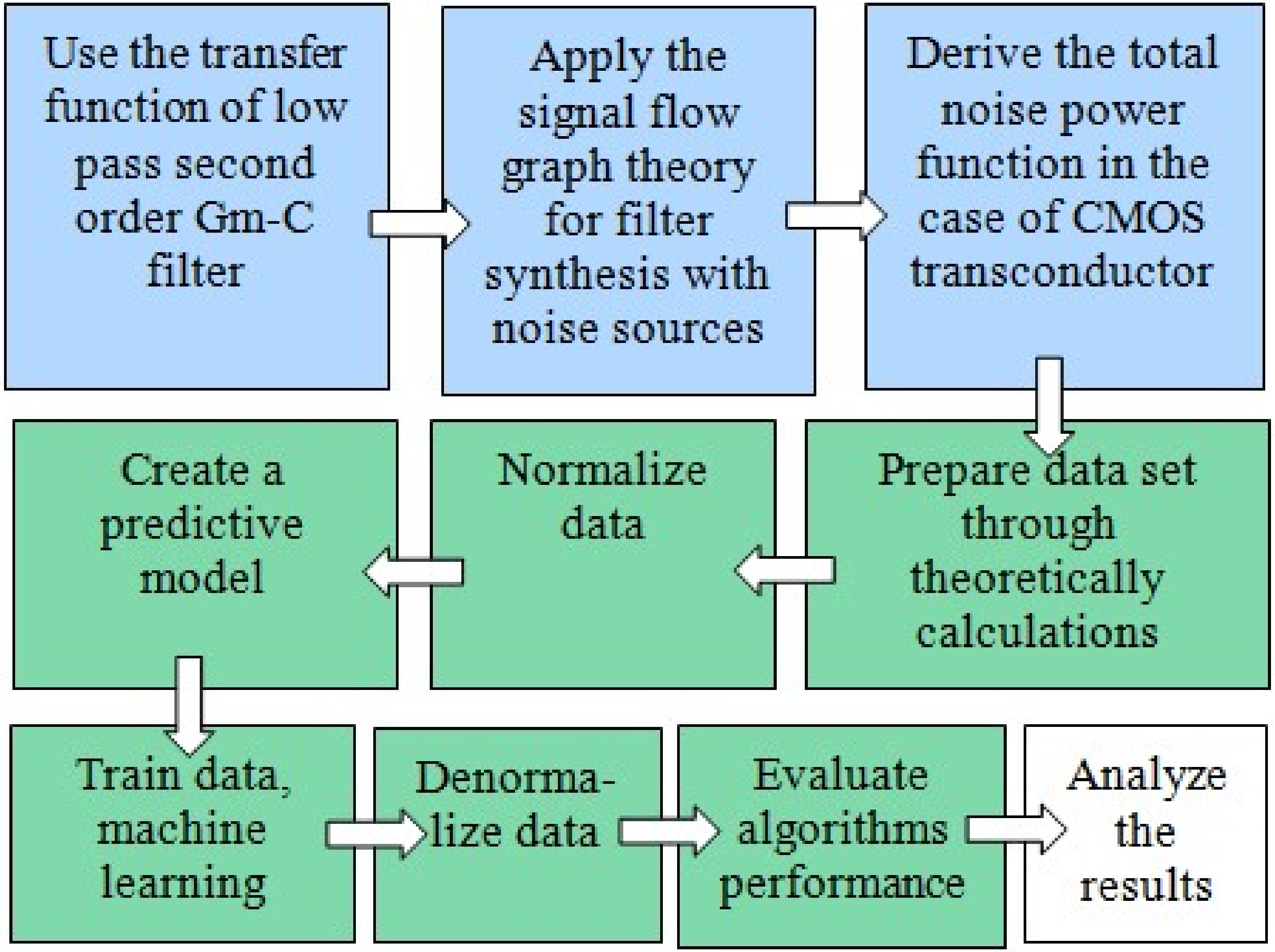
- Several methods are known for description the noise features and Gm-C filters noise behavior
- All of them are based on noise analysis for a concrete filter solution
- Exception is the general method proposed in (S. Koziel, S. Szczepanski and R. Schaumann, 2003) - such approach is suitable for implementation in the form of CAD tools

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN CIRCUIT MODELING

- One contemporary approach for modeling and analysis of electronic circuits and their parameters relays on algorithms in the areas of artificial intelligence, machine learning and deep learning

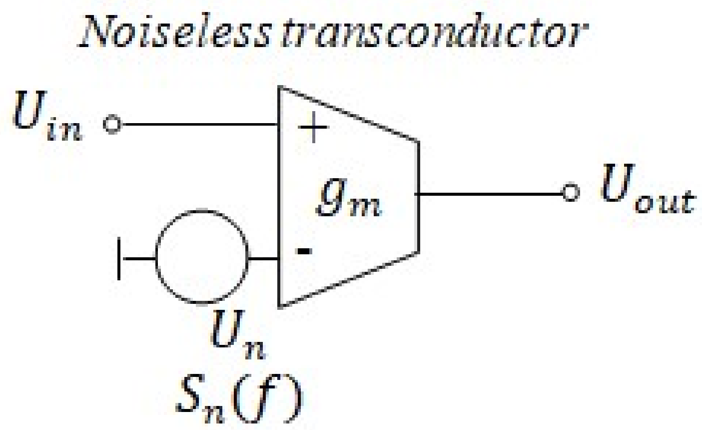


Research Method



FILTER MODELING WITH NOISE SOURCES

- Assumption
  - the capacitors in the Gm-C filter configuration are noiseless
  - noisy OTA with transconductance gm is modeled with a noiseless transconductor and an equivalent input referred noise voltage source Un, which spectral density is Sn(f)



FILTER MODELING WITH NOISE SOURCES

Spectral density of one input referred noise voltage source

$$S_n(f) = \frac{S_{th}}{g_m} + \frac{S_f}{f} = \frac{8kT}{3g_m} + \frac{A}{C_{ox}WLf} = K' + \frac{K''}{f}$$

The total output noise voltage spectral density taking into account the Gm-C filter topology

$$S_{ntotal}(f) = \bar{v}_n^2 = \sum_{i=1}^{k} S_{n_i}(f)|H_i(j2\pi f)|^2$$

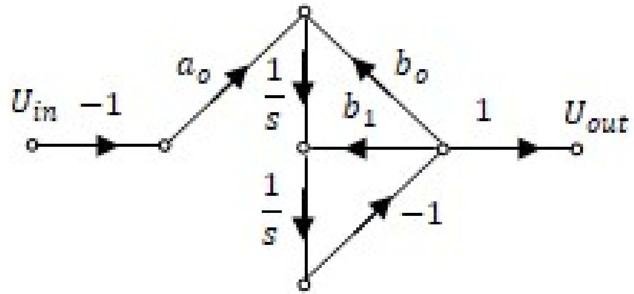
The total noise power

$$P_{nout} = \int_0^{\infty} S_{ntotal}(f)df$$

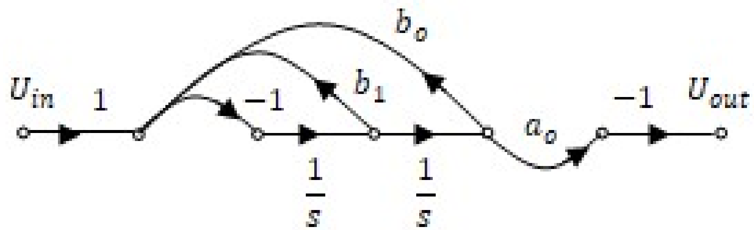
The transfer function of low pass second order biquad Gm-C filter

$$T(s) = \frac{U_{out}}{U_{in}} = \frac{a_0}{s^2+b_1s+b_0} = \frac{\omega_0^2}{s^2+\frac{Q}{\omega_0}s+\omega_0^2}$$

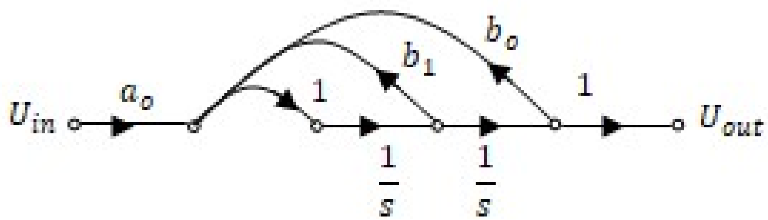
FILTER MODELING WITH NOISE SOURCES



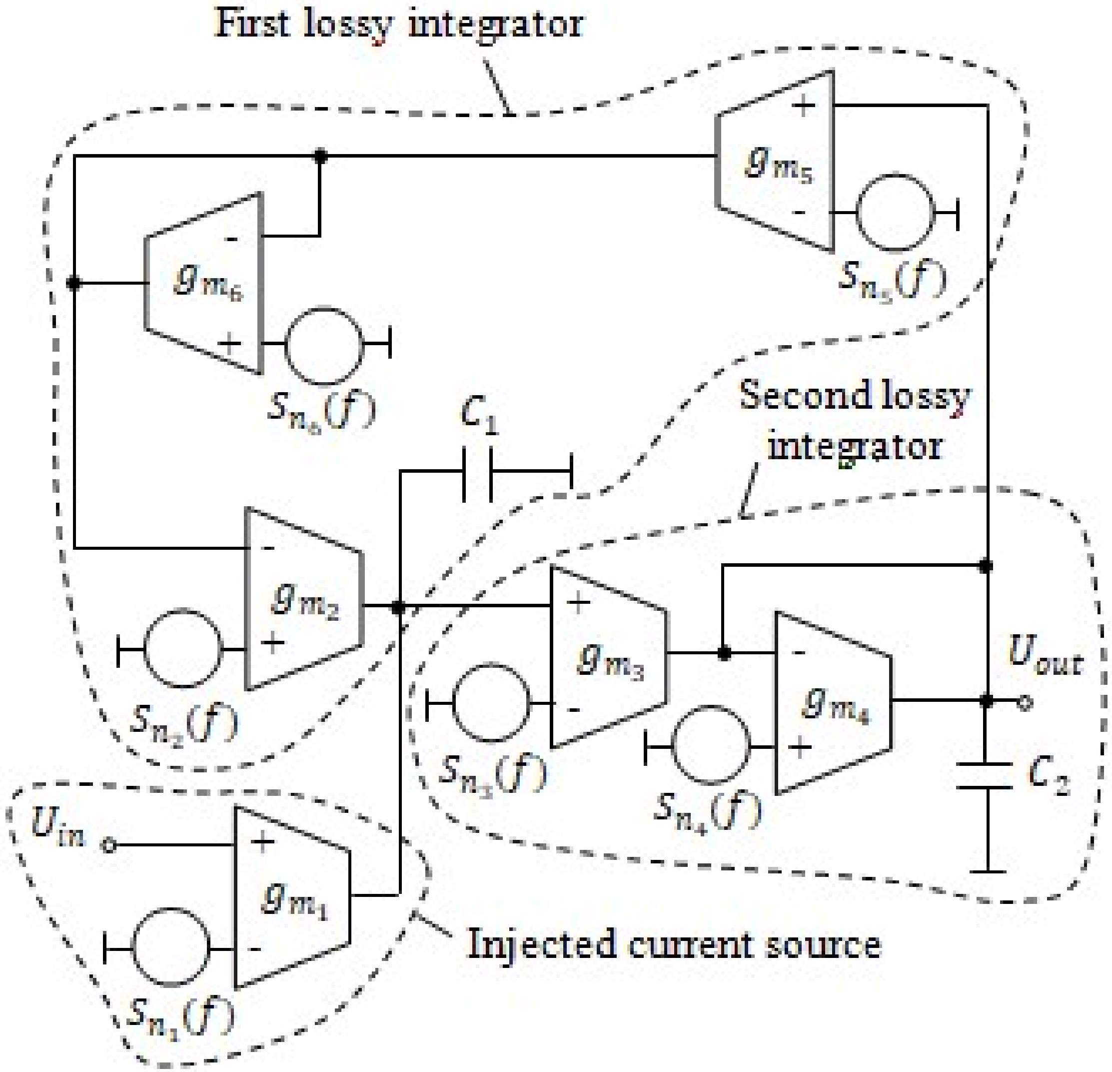
$$U_{out} = \frac{a_0}{s^2} U_{in} - \frac{b_1}{s} U_{out} - \frac{b_0}{s^2} U_{out}$$



Signal Flow Graph of second order buquad filter and equivalent transformations



Filter Modeling with Noise Sources



Filter Modeling with Noise Sources

$$H_1(s) = \frac{\frac{g_{m_2}}{C_1}}{s + \frac{g_{m_2} g_{m_5}}{C_1 \; g_{m_6}}} = \frac{g_{m_2} g_{m_6}}{s C_1 g_{m_6} + g_{m_2} g_{m_5}}$$

$$S_{out1}(f) = \frac{g_{m_2}^2 S_{n_2}(f) + g_{m_5}^2 S_{n_5}(f) + g_{m_6}^2 S_{n_6}(f)}{(2\pi f C_1)^2 g_{m_6}^2 + g_{m_2}^2 g_{m_5}^2}$$

$$H_2(s) = \frac{\frac{g_{m_3}}{C_2}}{s + \frac{g_{m_3} g_{m_4}}{C_2 \; g_{m_3}}} = \frac{g_{m_3}}{s C_2 + g_{m_4}}$$

$$S_{out2}(f) = \frac{g_{m_3}^2 S_{n_3}(f) + g_{m_4}^2 S_{n_4}(f)}{g_{m_4}^2 + (2\pi f C_2)^2}$$

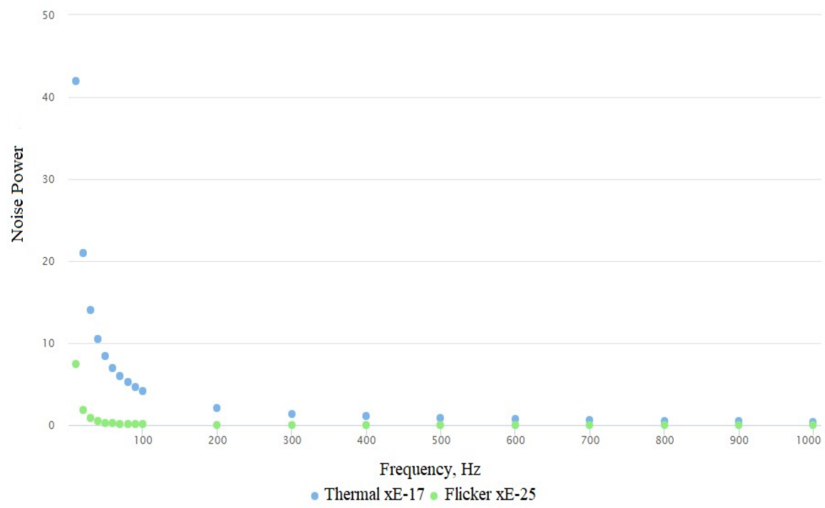
$$H_3(s) = \frac{g_{m_1} g_{m_3} g_{m_5}}{C_1 C_2 g_{m_6}}$$

$$S_{out3}(f) = \frac{g_{m_1}^2 S_{n_1}(f) + g_{m_3}^2 S_{n_3}(f) + g_{m_5}^2 S_{n_5}(f) + g_{m_6}^2 S_{n_6}(f)}{(2\pi f C_1)^2 (2\pi f C_2)^2 g_{m_6}^2}$$

$$S_{ntotal}(f) = S_{out1}(f) + S_{out2}(f) + S_{out3}(f)$$

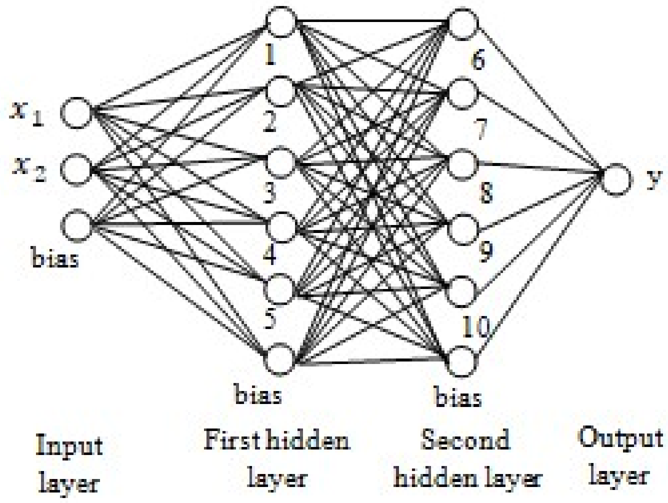
$$P_{nout} = \int_0^\infty S_{ntotal}(f) = \int_0^\infty S_n(f)\left(\frac{3 g_m^4}{(2\pi f C)^2 g_m^2 + g_m^4} + \frac{2 g_m^4}{(2\pi f C)^2 + g_m^2} + \frac{4}{(2\pi f C)^4}\right) \approx \int_0^\infty \frac{K_1}{f^2} + \frac{K_2}{f^3},$$

$$P_{nout} = -\left(\frac{K_1'}{f} + \frac{K_2'}{2 f^2}\right)$$



Machine Learning And Predictive Modeling

- Demonstration of the research method with ANN algorithm



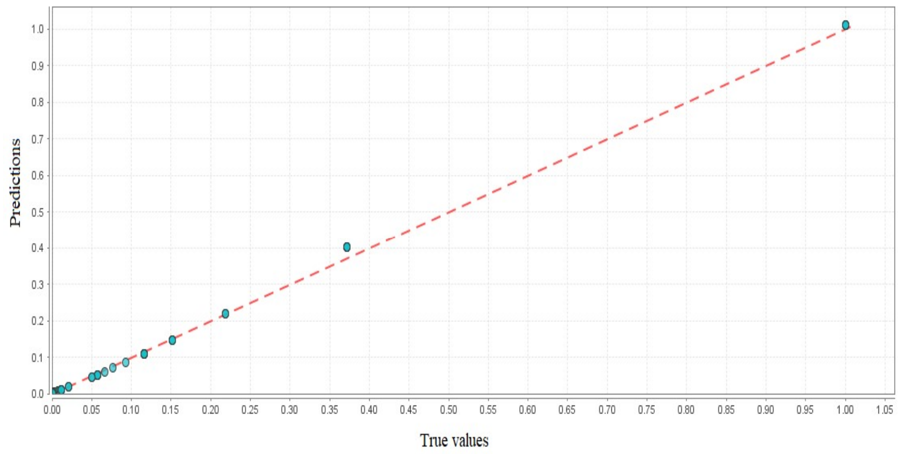
The constructed neural network

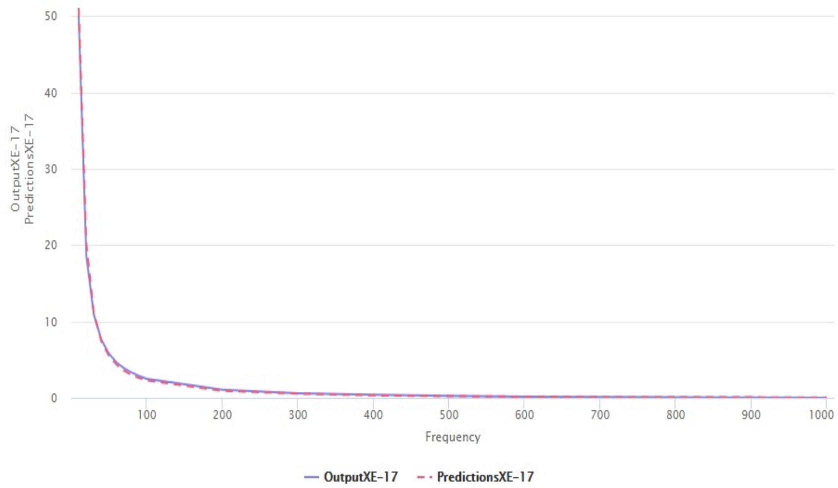
Row No.	output	prediction(o...	input1	input2
1	0.372	0.403	0.495	0.250
2	0.219	0.220	0.327	0.111
3	0.152	0.146	0.242	0.062
4	0.116	0.109	0.192	0.040
5	0.077	0.070	0.134	0.020
6	0.066	0.059	0.116	0.015
7	0.057	0.051	0.102	0.012
8	0.008	0.006	0.015	0
9	0	0.001	0	0
10	0.116	0.109	0.192	0.040

Deep learning and predicted output

MACHINE LEARNING AND PREDICTIVE MODELING

Deep learning – prediction chart

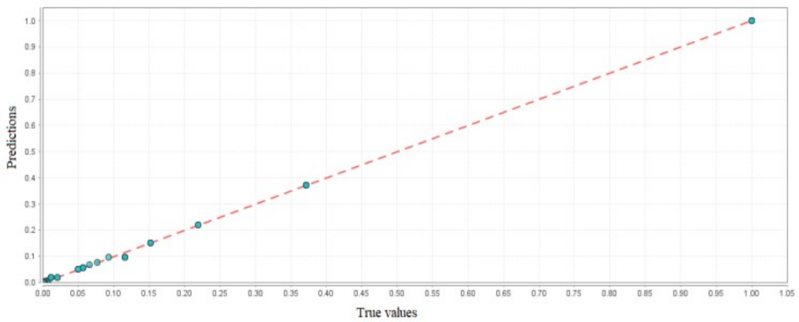




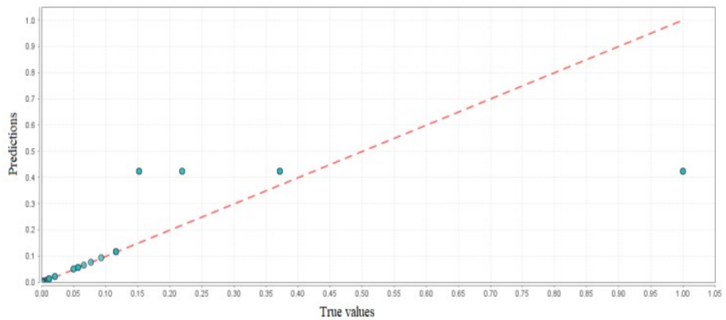
Theoretically calculated and predicted noise power

Machine Learning And Predictive Modeling

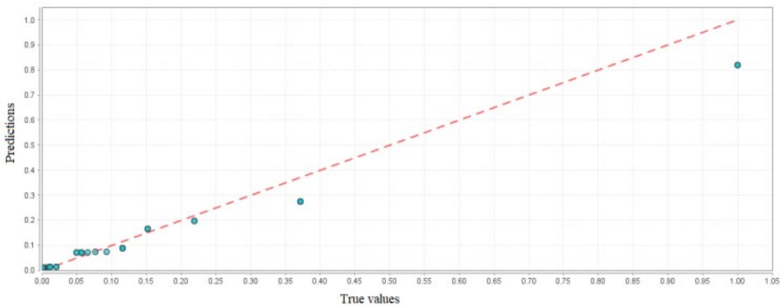
Prediction charts



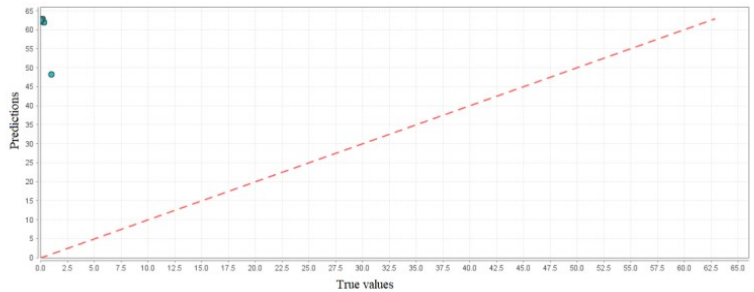
Decision Tree



Random Forest



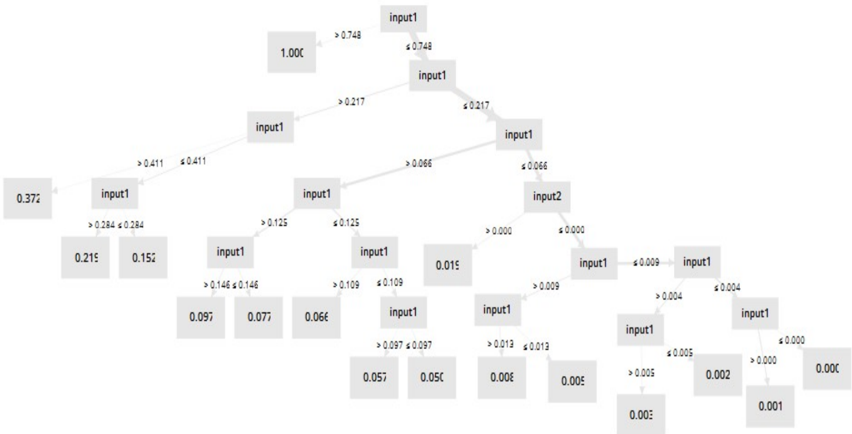
Gradient Boosted Trees



Support Vector Machines

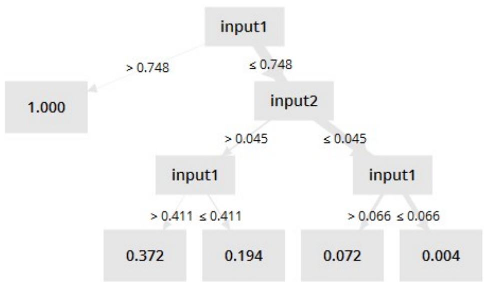
Machine Learning And Predictive Modeling

- Constructed trees



Decision Tree

Gradient Boosted Trees



Random Forest

$$IF\ 0.411 < input1 \leq 0.748\ AND\ input2 > 0.045\ THEN\ the\ predicted\ output\ IS\ 0.372$$

Machine Learning And Predictive Modeling

- Performance of machine learning algorithms

	Criterion			
Algorithm	RMSE	AE	REL	SE
ANN	0.008 $\pm$ 0.005	0.005 $\pm$ 0.002	11.85% $\pm$ 4.51%	0.000
DT	0.007 $\pm$ 0.004	0.004 $\pm$ 0.002	6.52% $\pm$ 3.99%	0.000
RF	0.036 $\pm$ 0.029	0.025 $\pm$ 0.016	32.60% $\pm$ 10.59%	0.002 $\pm$ 0.003
GBT	0.113 $\pm$ 0.078	0.051 $\pm$ 0.033	14.94% $\pm$ 10.76%	0.018 $\pm$ 0.018
SVM	61.947 $\pm$ 0.997	61.901 $\pm$ 1.098	99.80% $\pm$ 0.13%	3838.173 $\pm$ 122.279

→ ANN and Decision Tree algorithms are the best solutions for predicting the noise power in Gm-C filters. They are characterized with high accuracy.

Machine Learning And Predictive Modeling

- Processing time

	Criterion		
Algorithm	Training time	Scoring time	Total time
ANN	3s	109ms	895ms
DT	61ms	65ms	251ms
RF	140ms	152ms	962ms
GBT	3s	43ms	17s
SVM	1s	65ms	4s

CONCLUSION

- **Machine learning** that is described as a field of artificial intelligence proposes powerful techniques and algorithms for electronic circuits' analysis and design
- Studying the circuits' behavior through data about them allows a wide variety of predictive and analytical models to be created in support of engineers for decision making and problems solving

CONCLUSION

- Also, machine learning gives huge opportunities for **automation of engineering tasks** decreasing the needed time, efforts and resources
- Such approach could be implemented in CAD and EDA software in order to present a technique for design and analysis of electronic circuits and devices that could decide engineering problems with high quality and efficiency

Conclusion

- Some machine learning algorithms like tree-based ones not only point out the final solution, but also describe one or several paths for its achievement
- Other algorithms for deep learning which are based on artificial neural networks allow flexible and accurate approach for resolving the complexity of the problems
- It seems that some machine learning algorithms are suitable for performing a given engineering task while the others cannot deal with it

CONCLUSION

- This work explores the capabilities of machine learning to predict the noise power of Gm-C filters and it is proved that the learning algorithm should be precisely chosen for obtaining the best results
- Also, it is proved that a predictive model with high accuracy can be created to facilitate the performance of prognostic and analytical engineering tasks

CONCLUSION

- The future work will be focused on further exploration the capability of machine learning algorithms to facilitate engineering tasks, proposing possibilities for better understanding the behavior of electronic circuits
- The development of predictive and analytical models will be performed, exploring their valuable meaning in support of
  - Gm-C filters design – how the filter building blocks and elements to be chosen and arranged to form operable topology
  - filter analysis – what will be the filter and its building blocks reaction at different input stimuli

Picture is taken from: https://www.ansys.com/blog/what-is-crosstalk-electromagnetic-challenges-trends-electronics