Volume 57, Number 2, 2016

ACTA TECHNICA NAPOCENSIS
Electronics and Telecommunications

EXPERT SYSTEM FOR RECEIVER ARCHITECTURE SELECTION

Laura-Nicoleta IVANCIU, Gabriel OLTEAN
Bases of Electronics Department, Technical University of Cluj-Napoca, Romania
26-28 G. Bari□iu Street, Cluj-Napoca, Romania, phone:+40-264-401-471, laura.ivanciu@bel.utcluj.ro

Abstract: Selecting the architecture of a radiofrequency receiver is most often a truly tedious task, as it involves certain constraints that need to be met. This paper proposes an innovative method for choosing among various types of architectures, using a fuzzy expert system. It works with a set of rules, derived from the known characteristics of a finite number of possible receiver structures. The system suggests the architecture that best fits the requests, and also justifies the answer. The proposed solution makes a perfect tool for beginners or for educational purposes, as it also provides explanations regarding the reasoning process. The system proves to be a reliable and robust one, as demonstrated through various testing scenarios.

Keywords: *expert systems, fuzzy logic, RF receiver architecture.*

I. INTRODUCTION

The design process of any radiofrequency (RF) receiver begins with selecting a suitable topology/architecture. The designer has to choose between various types of architectures ([1]-[3]).

Multiple selection criteria, combined with competing design and implementation requirements, such as analog constraints, flexibility, noise level, integrability level, cost or power consumption ([4]) must also be kept in mind. All these constraints and limitations make the architecture selection task a tedious one, reserved for experts in the field, while simultaneously restricting it from novice users.

While expert knowledge is not always available, beginners in the field of RF receiver design could benefit from the development of an interactive and intuitive GUI tool, that allows them to better understand the selection process. This instrument should also deliver supplementary explanations on the reasons why certain architecture(s) is (are) suitable or not for the given design requirements.

Based on these premises, the idea of developing an expert system for selecting the RF receiver architecture comes naturally. An expert system works with knowledge from experts in the field, and is also able to justify its reasoning process ([5]). But how can the expert knowledge are integrated into the expert system? For instance, if an expert says that an architecture is highly flexible, what does this mean in terms of numerical values? Fuzzy logic comes as a great help in this matter, as it is able to work with imprecise data, and linguistic values, variables and rules that are similar to the human language [6]. More than that, fuzzy systems can easily capture and handle human reasoning, numerical and industrial data, or imprecise statements. Thus, an expert system based on fuzzy logic can successfully collect and work with qualitatively expressed information from the experts in the field.

Knowledge-based engineering is currently employed in system and process design, be it hardware or software ([7], [8]), in system or circuit level design tools that use knowledge-based expert systems, in order to provide the best topology or circuit device dimensions ([9]). FASY ([10]) selects a circuit topology, based on rules derived from specification requirements (e.g. gain, phase margin, 1/f noise for an Op-Amp). A fuzzy logic based decision handover system is proposed in [11], in order to reduce the ping-pong effect in a mobile communication network. The system effectively reduces the rate of unnecessary handovers, by making the handover decision based on a set of 68 rules.

This paper proposes a fuzzy logic based expert system for the selection of a suitable RF receiver architecture. The user inputs the design requirements into a GUI, and is provided the result of the selection process and various explanations regarding the reasons that led to a specific choice.

II. AN OVERVIEW OF RF RECEIVER DESIGN

An RF receiver front-end is the part of the receiver from the antenna to the analog-to-digital converter (ADC). The architecture of this structure refers to the specific topology of the blocks of which the receiver is composed of, which can be: filters, mixers, LNAs (low noise amplifier).

Receiver architectures for which the ADC works with low frequency signal can be classified as ([2], [3]): super-heterodyne; zero-IF or homodyne or direct conversion; low-IF; double-conversion. The advantages, drawbacks and some additional observations are synthesized in Table 1 ([1], [4], [12]).

III. THE EXPERT SYSTEM

For an expert system, the knowledge base is the most important aspect. Our expert system would decide which architecture is the most appropriate to be implemented, for a specific set of user design requirements. Starting from the findings in Table 1 and according with information in the literature, we can synthesize the expert knowledge and express it in a natural language, specific to human thinking, as presented in Table 2.

Manuscript received May 13, 2016; revised June 10, 2016

Table 1. Advantages and drawbacks of basic receiver architectures.

Receiver architecture	Advantages	Drawbacks	Notes
Super-heterodyne	high selectivity	image frequency	difficult to integrate
		off-chip components	difficult to reconfigure
Zero-IF	no image frequency	DC offset	easy to integrate
	no off-chip components	flicker noise	easy to reconfigure
Low-IF	low DC offset	image frequency	easy to integrate
	low flicker noise		easy to reconfigure
Double-conversion	low DC offset	many components	easy to integrate
	low flicker noise		easy to reconfigure
			strict ADC design constraints

Table 2. Knowledge expressed in natural language

Architecture / Design requirements	Super-heterodyne	Zero-IF	Low-IF	Double conversion
Analog constraints	high	moderate	low	moderate
Flexibility	low	low	any	any
Noise	low	high	high	moderate
Integrability	any	moderate or high	any	high

The terms "low", "moderate", and "high" are used to qualitatively describe the range of values for each design requirement. The term "any" means that the user should not worry about the qualitative value of that particular design requirement, because the best value always results for the specified architecture. For example, in the case of Super-heterodyne architecture, the resulted noise level is always low, which is better than moderate or high.

"Analog constraints" includes design constraints for the analog blocks of the architecture, such as filters, LNAs, and also the dynamic range limitations for the ADC. The term "Flexibility" refers to the architecture's potential to be modified. In RF receivers, the digitally implemented blocks provide increased flexibility, as they can be modified programmatically.

"Integrability" denotes the architecture's potential to be integrated. For instance, the Super-heterodyne architecture has a low integrability degree, as it contains external surface acoustic wave (SAW) filters ([2]).

For the implementation of the expert system, every column in Table 2 is formulated as a fuzzy rule. Every rule gives a measure of the fitting degree for a specific architecture (*FDA*), in accordance with the current values of the design requirements. Based on those fitting degrees, a decision referring to the architecture implementation is made and the result is presented and explained to the user.
The structure our expert system is presented in Figure 1.

The user interface is the vehicle that assures a very easy and intuitive communication of the user with the expert system. The user provides the current values of the design requirements, and the expert system will display its decision and explanations as bar graphs and text.

The knowledge of the experts are encapsulated in the "Fuzzy knowledge base" as fuzzy sets for design requirements and as fuzzy rules for the relations between design requirements and architectures. The fuzzy sets for the design requirements: Analog constraints, Integrability, and Noise are presented in Figure 2. For the fourth design requirement, Flexibility, only two fuzzy sets, "low" and "high", were considered, uniformly distributed across the full universe of discourse. For all design requirements, the universe of discourse is considered to be [0, 100].

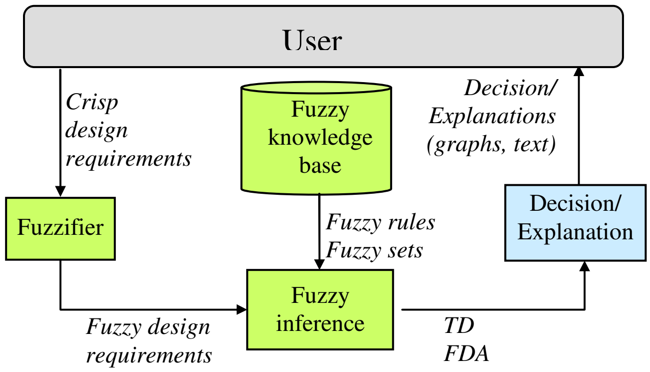

Figure 1. Structure of the expert system

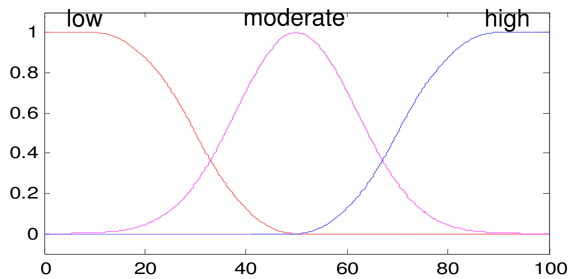

Figure 2. Fuzzy sets for Analog constraints, Integrability, and Noise.

The rule base contains four rules (according with Table 2 – one rule per architecture). As an illustration, for column 1, the corresponding fuzzy rule is:

If ***Analog constraints is high*** and ***Flexibility is low*** and ***Integrability is low*** then ***Super-heterodyne architecture is fit***.

The fitting degree of architecture (*FDA*) is computed by evaluating the truth degree (firing degree) for the fuzzy rules. This materializes in the "Fuzzy inference" block. Fuzzy design requirements (singleton fuzzification of the crisp design requirements) are used to evaluate the truth degree (*TD*) of each simple premise of fuzzy rules for the current design requirements. Then, the truth degree of each rule - that is in fact the fit degree of the architecture in the rule consequence - is computed as the minimum value of *TDs* in its premises:

$$FDA_i = \min_j (TD_{ij}) \qquad (1)$$

where FDA_i is the fit degree for i^{th} architecture (i=1,2,…,4) and TD_{ij} is the truth degree of the simple premise j in rule i.

The "Decision/ Explanation" block processes *FDAs* and *TDs* in order to make recommendations to the user towards architecture implementation and to explain its recommendations using bar plots and text.

The operation of the expert system is described below:

Start
Read current design requirements
Evaluate fuzzy rules: TD_{ij}, FDA_i
Plot bar graphs for TD_{ij} *and* FDA_i
FDAmax = max(FDA_i)
If FDAmax ≥ FD_Th
ARH = architecture with maximum FDA
message : "The architecture ARH can be implemented"
{*supplementary text explanation*}
Elseif FDAmax ≥ FD_Th_m
ARH = architecture with maximum FDA
message: "The architecture ARH can be marginally implemented. A special attention should be paid for the design requirements with minimum TD"
{*supplementary text explanation*}
Else
message (*No architecture can be implemented*)
{*supplementary text explanation*}
End

Two crisp thresholds are used for *FDAmax* to make the final decision for architecture implementation:

- *FD_Th* (default value: 0.85);
- *FD_Th_m* (default value: 0.75).

FDAmax below 0.75 means that it is not possible to implement the architecture. If *FDAmax* is above 0.85 it means that the architecture can be implemented for sure, while a value between 0.75 and 0.85 means that it is possible to implement the architecture, but special attention should be paid to the design requirement that gives the minimum value of the *TD* of its associated premise. The best situation for implementing the architecture is the one having *FDA* = 1, meaning that all design requirements can be fully satisfied using that architecture.

IV. IMPLEMENTATION AND RESULTS

The user interface of our design tool for receiver architecture selection is represented in Figure 4. It contains three main panels:

- "*Design requirements*" – the user inputs current values for each design requirement by editing in the associated text field or adjusting the bar sliders. To the left of each slider, a colored bar suggests the linguistic values of the design requirements, as they were defined in the fuzzy sets in Figure 2;
- "*Information about architectures*" – presents qualitative information regarding the necessary design requirements combinations that can be implemented by each architecture;
- "*Results*" – in this panel, the user can see the results and explanations provided by the expert system. In the bottom part, the values of *TDs* evaluated for the current design requirements are displayed as bar graphs (the first four columns), for each receiver architecture. The fifth column indicates the *FDA* value, computed as the minimum value between the corresponding *TDs*.

If certain architecture is possible to be implemented, its associated bar graph is plotted in blue. To the top-right of this panel, a synthesis is presented by plotting a bar graph for the *FDAs*. For the architecture possible to be implemented, the bar is once again colored in blue. Extra text explanations and comments are display in the top-left region of the panel.

Detailed numerical results for one set of crisp design requirements (Set 1) are presented in Table 3. The same values for design requirements were also used in Figure 3, so the reader can easily follow the graphical representation. For example, for the Super-heterodyne architecture, the truth degrees (*TD*) of the partial premises of the fuzzy rule are:

- 0.789 for Analog constraints = 77 ("Analog constraints is high");
- 1 for Flexibility = 15 ("Flexibility is low");
- 0.939 for Integrability = 17 ("Integrability is low");
- 1 for Noise = 73 (Noise can have any value – "any")

The fit degree of Super-heterodyne architecture (*FDA*) is given by the value of *TD* for Analog constraints, because it has the minimum value of 0.789.

Table 3. Results for Set 1 of Design Requirements

Crisp design requirements Set 1		**Receiver architectures**							
		Super-heterodyne		**Zero – IF**		**Low – IF**		**Double Conv.**	
Name	**Val.**	***TD***	***FDA***	***TD***	***FDA***	***TD***	***FDA***	***TD***	***FDA***
Analog cons.	77	**0.789**		0.08		0		0.08	
Flexibility	15	1	**0.789**	1	0	1	0	1	0.023
Integrab.	17	0.939		0		0		0.023	
Noise	73	1		1		1		0.839	
Results / Explanations:									
For the selected values of the design requirements the architecture "Super-heterodyne" can be marginally implemented. Its fit degree is 0.789, close to 1 (maximum possible value). A special attention should be paid for the design requirement "Analog constraints" that is the least fulfilled requirement, its truth degree being only 0.789. Supplementary information related to the calculation of fit degree can be seen on the blue graph Super-heterodyne below.									

The fit degrees (*FD*) for the remaining architectures are: 0 for Zero-If, because the truth degree of the premise "Integrability is high" is 0; 0 for Low – IF, because both truth degrees of the premises "Analog constraints is low" and "Integrability is high" are 0; 0.023 for Double Conversion because the truth degree of the premise "Integrability is moderate" is 0.023.

The final decision and text explanations are presented in the last row in Table 3. Only the Super-heterodyne architecture is possible to be implemented because its *FDA* is greater than the *FD_Th_m*=0.75 threshold. But, because it is also below the other *FD_Th*=0.85 threshold, it is not so easy to satisfy all the design requirements, especially the one with the minimum truth degree (Analog constraints).

Table 4 presents the results for another set of design requirements (Set 2) that correspond to a situation where no architecture can be implemented. In this case, the Zero-IF architecture has the maxim value of its fit degree (0.458) but this is too low (below the threshold for marginal implementation), so no architecture can be used for SET 2 design requirements. The user can analyze which are the critical design requirements that hinder the implementation of Zero-If architecture: Analog constraints with *TD* =0.458 and Integrability with *TD* = 0.595. To implement this architecture, it is necessary to satisfy the following premises: "Analog constraints is moderate" and "Integrability is high".

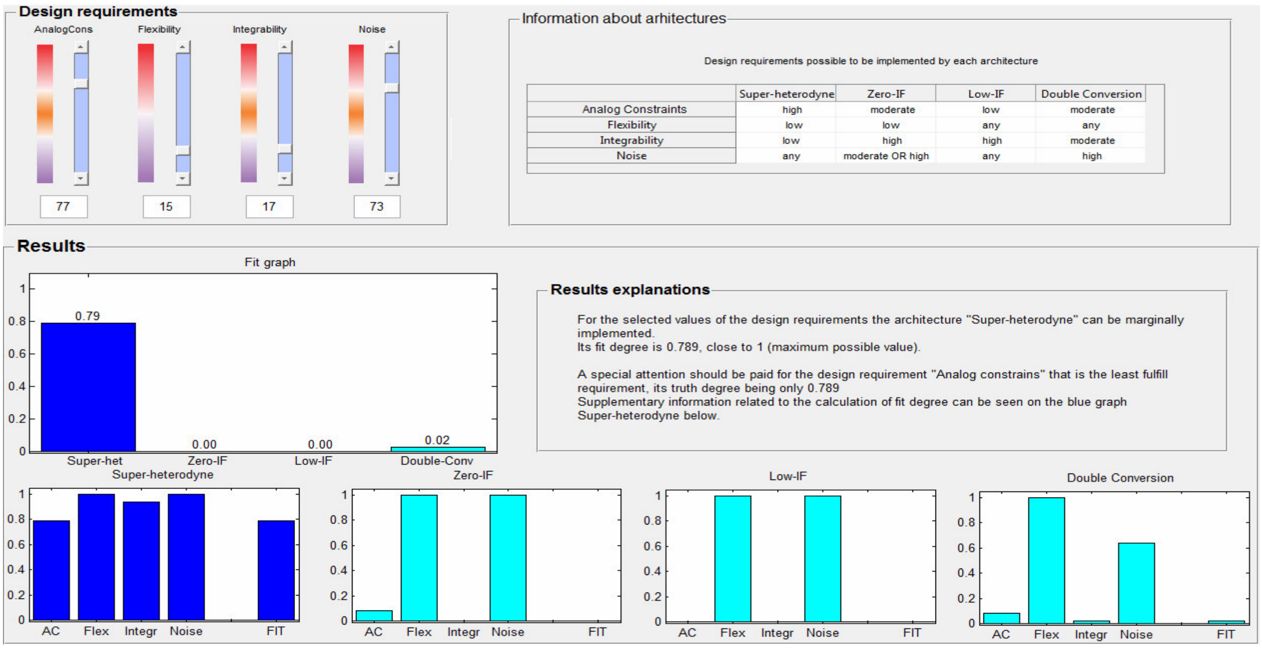

Figure 3. Front-end of the receiver architecture selection tool

Table 4. Results for Set 2 of Design Requirements

Crisp design requirements Set 2		Receiver architectures							
		Super-heterodyne		Zero – IF		Low – IF		Double Conv.	
Name	**Value**	*TD*	*FDA*	*TD*	*FDA*	*TD*	*FDA*	*TD*	*FDA*
Analog cons.	**35**	0	0	0.458	0.458	0.281	0.281	0.46	0.18
Flexibility	**7**	1		1		1		1	
Integrab.	**72**	0		0.595		0.595		0.18	
Noise	**82**	1		1		1		0.92	
Results / Explanations: For the selected values of the design requirements no architecture can be implemented. The maximum value of the fit degree is 0.458 for the "Zero-IF" architecture. To be implemented, an architecture should have a fit degree of at least 0.75. The calculation of fit degrees of all architectures for the current design requirements can be seen on the graphs below.									

V. CONCLUSIONS

The paper describes the implementation of a fuzzy expert system for selecting the most appropriate architecture to implement a RF receiver, for a given set of design requirements.

This application is primarily intended for the educational process, for novice designers in the field, by providing an easy-to-use design tool capable to show detailed explanations regarding the reasoning and decisions involved in selecting the possible architectures to be implemented.

The user can explore and understand different design scenarios, in order to gain deep insight into the fascinating and very complex field of radiofrequency receiver design.

ACKNOWLEDGEMENT

This work was supported by a grant of the Romanian MEN–UEFISCDI, project number PN-II-PT-PCCA -2013-4-1791, contract number 296/2014.

REFERENCES

[1] Jan Mikkelsen, “Front-End Architectures for CMOS Radio Receivers”, Division of Telecommunications, Aalborg University, Denmark, 1996. [Online]. Available: http://www.inst.bnl.gov/~poc/wireless/rf_architectures.pdf [Accesed: June 10th, 2016].

[2] B. Razavi, *RF Microelectronics, 2nd edn.*, Prentice Hall, New Jersey, 2011.

[3] T.H. Lee, *The Design of CMOS Radio-Frequency Integrated Circuits, 2nd edn.*, Cambridge University Press, Cambridge, 2003.

[4] P. Mak, Seng-Pan U, R.P.Martins, “Transceiver architecture selection: Review, State-of-the-art survey and case study”, *IEEE Circuits and Systems Magazine*, vol. 2/2007, pp. 6-25, 2007.

[5] E. Turban, R. Sharda, D. Delen, *Decision Support and Business Intelligence Systems, 9th ed.* Pearson Education, New York, 2013.

[6] R. Eberhart Y. Shi, *Computational Intelligence. Concepts to Implementations.*, Elsevier, Amsterdam, 2007.

[7] F. Tian, M. Voskuijl, “Knowledge Based Engineering to support electric and electronic system design and automatic control software development”, *IEEE 32nd Digital Avionics Systems Conference (DASC)*, 2013.

[8] P. Zheng, G. Zhao, V.H. Torres, J. Ríos, “A knowledge-based approach to integrate Fuzzy Conceptual Design Tools and MOKA into a CAD system”, *IEEE Proceedings of 7th Intl. Comp. and Conv. Tech. (ICCCT)*, pp. 1285-1291, 2012.

[9] M. Fakhfakh, E. Tlelo-Cuautle, R. Castro-Lopez, *Analog/RF and mixed-signal circuit systematic design,* Springer Verlag, Berlin, 2013.

[10] A. Torralba, J. Chavez, L.G. Franquelo, “FASY: a fuzzy-logic based tool for analog synthesis”, *IEEE Trans. on Computer-Aided Design of Integrated Circuits and Systems*, vol. 15(7), pp.705-715 , 1996.

[11] K.L. Tsai, H.Y. Liu, Y.W. Liu,”Using fuzzy logic to reduce ping-pong handover effects in LTE networks”, *Soft Computing*, vol. 20(5), pp. 1683-1694, 2015.

[12] Y. Lakys, A. Fabre, “Multistandard transceivers: state of the art and a new versatile implementation for fully active frequency agile filters”, *Analog Integrated Circuits and Signal Processing,* vol. 74(1), pp.63-78, 2013