Statistical Optimization of Filters in Radiocommunication Systems in IESD Simulator

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Abstract - The papers presents the methodology for statistical design of band pass filters set in radiocommunication systems. The function constraints are defined from norms. Monte Carlo simulations and optimizations are performed with the statistical simulator IESD and Orcad PSpice. Both design centering and optimal tolerancing optimizations are considered.

Keywords - Band pass filters; Norms for radiocommunication systems; Statistical optimization; Monte Carlo simulation

I. Introduction

A research was performed to develop specific methodologies for statistical optimization of different types of electronic circuits. The general methodology for statistical design using the statistical simulator IESD [3] and the PSpice tool is proposed in [4]. Specific applications of this methodology were developed for a voltage regulator circuit in [2] and for a TV module in [5]. The paper presents a new specific application of the general statistical optimization methodology developed for a set of band pass filters in radiocommunication systems. A set of band pass filters for community antennas system was proposed in [1]. First the design from [1] is estimated through nominal AC and noise simulations in PSpice. An improved solution was proposed to fit better the frequency band constraints for the radio and TV channels studied. The constraints for the band pass filters in the community antenna are taken from the norms given in [6] by Bulgarian telecommunications company. Then the specific statistical optimization methodology is developed. The statistical optimization goal function is defined. Statistical analysis in AC(NOISE) and TIME domain are performed. Circuit parameters, yield and fail are estimated. Two statistical optimization methods [4,7]: design centering and optimal tolerancing are performed.

II. Specific Methodology for Statistical Optimization of Band Pass Filters for Community Antenna Systems

The steps of the specific statistical design methodology are:

- Nominal simulation, estimation and adjusting of the initial design for the set of band pass filters corresponding to the frequency band constraints for the radio and TV channels.
- Constraints definition following the norms for radiocommunication systems in [6].
- Nominal analysis and estimation of the circuit performance.
- Definition of critical performance parameters for each filter.
- Statistical optimization of each filter with objective 100% yield and 0% Fail through:
  - Design centering
  - Optimal tolerancing.
- Statistical estimation of the optimized design

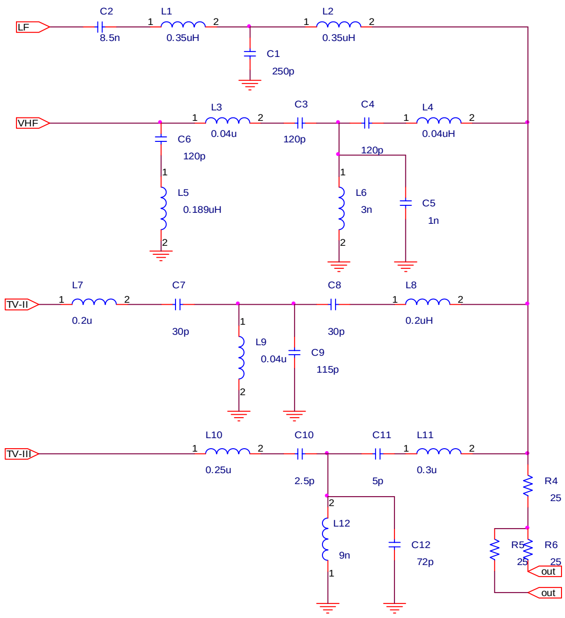

Figure 1. New design for the Band pass filters set for community antenna systems from [1] obtained after nominal simulations in ORCAD (PSpice)

III. Nominal Design

The four band pass filters separate 4 channels:
2 radio channels LF (+ MF, HF,with amplitude modulation) , with frequency band **ΔF=(150kHz-26MHz)** and VHF (with frequency modulation) with **ΔF=66MHz-108MHz**,
and 2 TV channels TV-II with **ΔF=(47MHz-100MHz)** and TV-III with **ΔF=(173MHz-230MHz).**

PSpice simulation of the original circuit with the C_i, L_i values from [1] doesn't meet the frequency band constraints for the 4 channels. New design values were defined and the design was corrected as presented in Table I. The set of filters from [1] with the parameters values from Table I is presented on Figure 1. Figure 2 presents the 4 filters in the set, separated from each other in order to perform the nominal and statistical simulations in PSpice and IESD tools.

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TABLE I

Correction of the nominal design from [1] after ORCAD (PSpice) simulation

a) New values for the capacitors

C	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Value from [1]	150pF	Not available	33pF	33pF	120p	18pF	10pF	10pF	100pF	3.9pF	3.9pF	72pF
New value	250pF	8.5nF	120pF	120pF	1nF	120p	30p	30pF	115pF	2.5pF	5pF	22pF

b) New values for the inductors

L	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
Value from [1]	0.226µH	0.226µH	0.189µH	0.133µH	0.189µH	0.189µH	0.174µH	0.149µH	0.023µH	0.066µH 0.066µH 0.131µH	0.089µH	0.131µH
New value	0.35µH	0.35µH	0.04µH	0.04µH	0.189µH	3nH	0.2µH	0.2µH	0.04µH	0.25µH	0.3µH	9nH

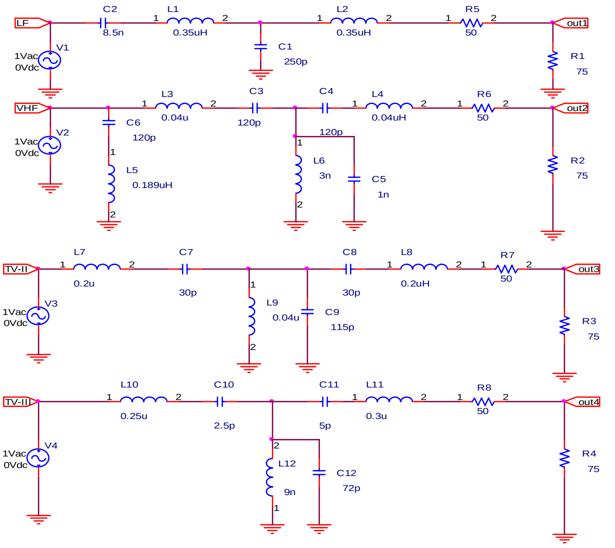


Figure 2. Four band pass filters for simulations with IESD and PSpice

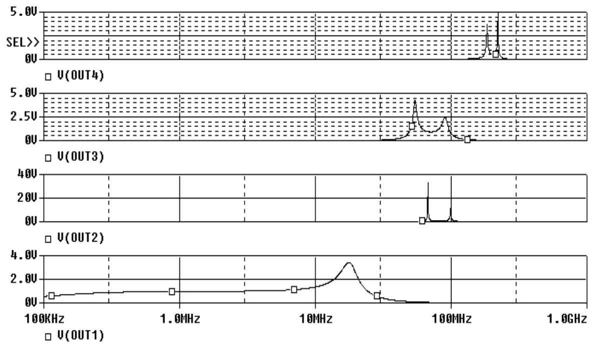


Figure 3. Output voltage curves in the different channels

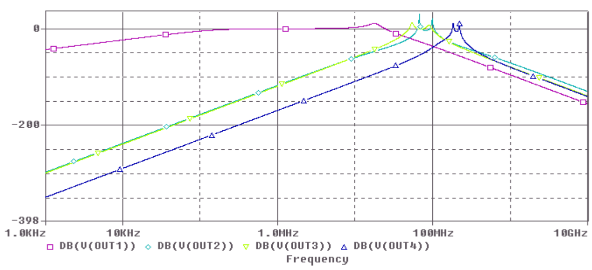


Figure 4. Output voltage in [db]

Nominal simulations in AC(Noise) domain for the set of band pass filters is performed in PSpice. Figure 3 presents the output voltage curves and Figure 4 presents the output voltage in [db]. Figure 5 presents the output noise and the S/N ratios in frequency domain for the 4 channels. Figure 6 presents the group delays. Table 2 presents the nominal values of the circuit parameters for the 4 filters as well as the limit imposed on the circuit. The limits for the TV pole gains, S/N ratio and group delay for the TV channels I and II are taken from the norms in [6].

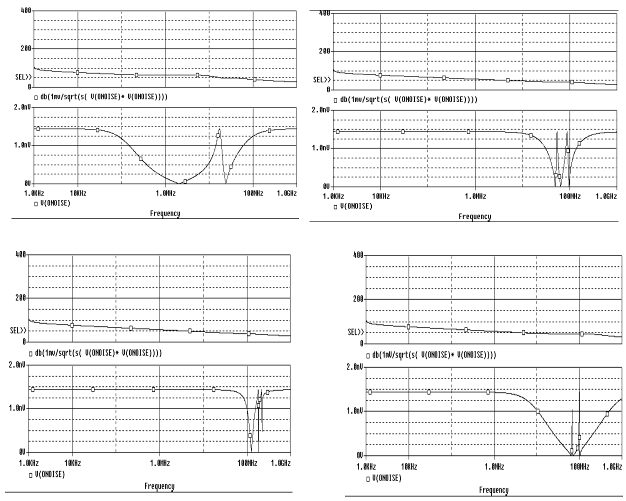


Figure 5. Output noise and S/N ratio for the four band pass filters

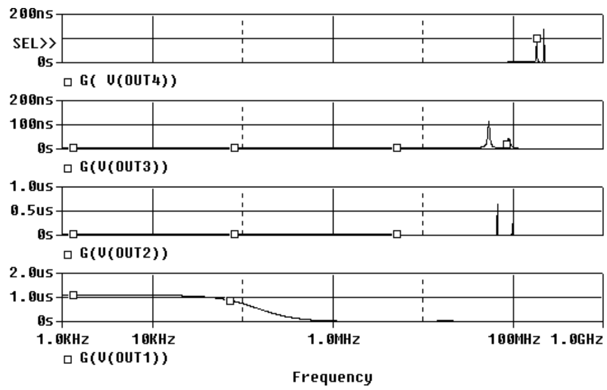
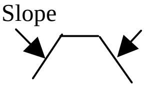


Figure 6. Group delays of the four band pass filters

TABLE II

Circuit parameters from nominal simulation and norm limits

Filter	LF (+MF,HF)	VHF	TV – II channel	TV – III channel	Limits
Frequency band ΔF (fL-fH)	150kHz-26MHz	66MHz-108MHz	47MHz-100MHz	173MHz-230MHz	**fL ± 10%** **fH ± 10%**
Pole gain	Before R5: P1=10.657dB At node out1: P1=6.27db	Before R6: P1=30dB P2=18.544dB At node out2: P1=20.88dB P2=16dB	Before R7: P1=11dB P2=3.39dB At node out3: P1=8.15dB P2=3.54dbdB	Before R8: P1=11db P2=14db At node out4: P1=6.6dB P2=8.37dbdB	Norms for TV channels II, III from [6] **Strongest limit ≤6db** **Lightest limit ≤16db**
S/N ratio for the lower and higher limit frequency in ΔF	S/N(fL)=66db S/N(fH)=49db	S/N(fL)=45db S/N(fH)=45db	S/N(fL)=42db S/N(fH)=41db	S/N(fL)=36db S/N(fH)=35db	Norms for TV channels II, III from [6] **Strongest limit ≥57db** **Lightest limit ≥ 48db**
Group delay	VG(fL)=535ns VG(fH)=8.5ns	VG(fL)=26ns VG(fH)=1.22ns	VG(fL)=10ns VG(fH)=6.7ns VGmax=112ns (154MHz)	VG(fL)=3.34ns VG(fH)=1ns VGmax=136ns (220MHz)	Norms for TV channels II, III from [6] **Strongest limit ≤100ns** **Lightest limit ≤ 200ns**
Slope 	20db/dec -60db/dec	60db/dec -60db/dec	60db/dec -60db/dec	60db/dec -60db/dec	-

For the LF (+MF,HF) band pass filter the S/N ratio is 57db at 11MHz and at that frequency it goes down fast with about 10db. The S/N ratios for the channel TV-II are at the lowest deterioration limit permitted in [6] (48-7)db. The S/N ratios for the channel TV-III are out of the norms and some design improvement has to be performed on the circuit for these parameters. More powerful emitter has to be used for TV- III.

IV. STATISTICAL OPTIMIZATION METHODOLOGY

A. Definition of the goal function

The objective is to perform design centering and optimal tolerancing to the circuit in order to obtain 100% Yield and 0% Fail with the given constraints from Table II.

The goal function for the statistical optimization of the band pass filters set is defined as follows:

Opt Val(C_i, i=1,12, L_j=j=1,12) and Max Tol(C_i, i=1,12, L_j, j=1,12), Yield=100%, Fail=0%, {fL(LF+MF,HF)=150kHz±10%, fH(LF+MF,HF)=26MHz±10%, fL(VHF)=66MHz±10%, fH(VHF)=108MHz ±10%, fL(TV-II)=47MHz±10%, fH(TV-II)=100MHz±10%, fL(TV-III)=173MHz±10%, fH(TV-III)=230MHz±10% , minP$_1$(LF+MF,HF), min $P_{1,2}$(VHF), $P_{1,2}$(TV-II)≤16db, $P_{1,2}$(TV-III) ≤16db,VG(TV-II) ≤200ns, VG(TV-III) ≤200ns, S/N(fL)≥48db, S/N(fH))≥48db}

The design centering and optimal tolerancing are illustrated for the LF(+MF,HF) band pass filter. The goal function for the LF(+MF,HF) band pass filter is defined as:

Opt Val($C_{1,2}$, $L_{1,2}$) and Max Tol($C_{1,2}$, $L_{1,2}$), Yield = 100%, Fail=0%, fL(LF+MF,HF)=(135-165)kHz, fH(LF+MF,HF)=(23.6-28.6)MHz, min P1, S/N(fL)≥48db, S/N(fH))≥48db}

B. Design centering of the LF(+MF,HF) channel filter

The design centering is performed in order to decrease the pole gain in the allowed frequency band and S/N ratio. A Monte Carlo AC analysis with 10% tolerances and uniform distribution for C1, C2, L1, L2 is performed. The runs with the smallest results for P1 are considered and the frequency band ΔF are considered for each case. The gain in P1 was decreased from 10.558db to 10.05db, with frequency band ΔF=148kHz – 26MHz which corresponds to the constraints. The pole gain decrease is very strongly related to the value of ΔF, so that solution is a reasonable compromise.

TABLE III

Results for the element values after design centering

Element	C_1	C_2	L_1	L_2	P_1	fL	fH	S/N(fL)	S/N(fH)
Initial value	250pF	8.5nF	0.35μH	0.35μH	**10.657**	150kHz	26MHz	66db	49db
Optimized value	234pF	9nF	0.38μH	0.33μH	**10.05**	148kHz	26MHz	66.7db	48.7db

C. Optimal tolerancing of the LF(+MF,HF) channel filter

Table IV presents the statistical optimization steps for the optimal tolerancing of the LF (+MF,HF) band pass filter. The optimal tolerancing objective is to select the maximal tolerance values that guarantee 100% yield and 0% Fail. The statistical simulation data show that the S/N ratio and the group delay are not sensitive to tolerances and their values correspond to the constraints. The critical parameters for the statistical optimization are the frequency band limits fL and fH, and the pole gains.

TABLE IV
Steps in optimal tolerancing procedure

Element Value Parameter	Tolerances at step1	Step2	Step3	Step4	Step5	Step6	Step7
C1	1%	2%	5%	5%	**10%**	10%	10%
C2	1%	2%	5%	10%	**5%**	5%	5%
L1	1%	2%	5%	5%	**5%**	10%	5%
L2	1%	2%	5%	5%	**5%**	5%	10%
P1	(9.895-10.21)db	(9.772-10.29)db	(9.4-10.697)db	(8.917-11.01)db	**(9-10.45)db**	(8.75-11.1)db	(8.95-10.5)db
fL	(141-148.5)kHz	(138.6-151)kHz	(135-159)kHz	(121-162)kHz	**(136-156)kHz**	(131-159)kHz	(129-159)kHz
fH	(25.731 -27.05)MHz	(25.7-27)MHz	(25.3 -28)MHz	(23.85 -27.8)MHz	**(24.4-28.5)MHz**	(23.6-30)MHz	(24-29.5)MHz
S/N(fL)	(66.6-66.7)db	(66.5-66.7)db	(66.4-66.8)db	(66.3-66.8)db	**(66.6-67.2)db**	(67-67.1)db	(67-67.1)db
S/N(fH)	(48.6-48.7)db	(48.5-48.8)db	(48.3-49)db	(48.3-49.1)db	**(48.2-49.1)db**	(48.3-49)db	(48-49)db
VG(fL)	(530-532)ns	(530-532)ns	(529-532)ns	(517-536)ns	**(526-535)ns**	(529-532)ns	(529-533)ns
VG(fH)	(8-8.5)ns	(7.5-8.5)ns	(5.9-10)ns	(48.3-49.1)ns	**(6.5-13.1)ns**	(6.9-10)ns	(8-10.1)ns
Yield/ Fail	Yield100% Fail 0%	Yield100% Fail 0%	Yield100% Fail 0%	Yield 67% Fail 33% on FL	**Yield100% Fail 0%**	Yield 60% Fail 40%	Yield 60% Fail 40%

The optimal solution for the LF (+MF,HF) band pass filter is:

C1=234pF±10%,C2=9nF±5%, L1=0.38μH±5%, L2=0.33μH±5%

Figure 7 illustrates the statistical time domain response for the output voltage of the LF (+MF,HF) band pass filter with an unitary input pulse with 1μs period (the frequency 1MHz ∈ ΔF[LF+MF,HF]). This simulation can be the basis for rise time and pulse peaks estimation, as defined in the norms from [6].

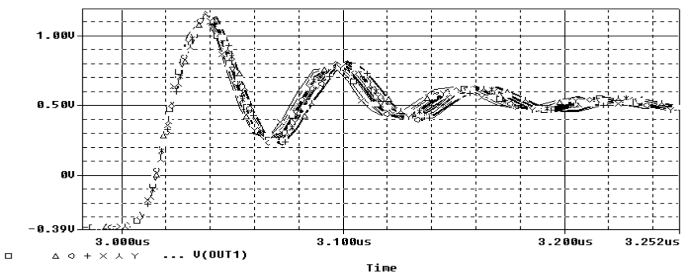


Figure 7. Monte Carlo simulation of the output voltage in Time area with an unitary input pulse, 1μs period.

The three other filters are optimized nominally and statistically following the same methodology.

CONCLUSION

The paper presents a methodology for statistical optimization of a set of band pass filters in community antenna system. Starting from a previously published initial circuit, nominal and statistical estimations and optimizations are performed in order to obtain performance corresponding to the constraints from the radiocommunication systems norms, 100% yield and 0% fail. The new approach defined permitted to improve the high sensitive band pass filters system following the very strict and strongly correlated constraints. The statistical design methodology developed for the band pass filters system completes the previously developed methodologies for voltage regulator circuits and TV modules. It confirms again the advantages of the statistical design approach in design for manufacturing in radiocommunications systems. The methodology can be implemented for other selective circuits. The general approach will be specified for other types of circuits.

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