INDUCTORS INFLUENCE OVER THE DC-DC CONVERTER PERFORMENCE

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This paper concerns the technological limitation of fully monolithic dc-dc converters. Two types of circuits were investigated on AMS CMOS 0.35 µm process. Comparison between efficiency results of architectures used on-chip and off-chip filter's inductors are made. The inductors influence over the dc-dc converters performance is evaluated. Input voltage of 3.6V, which is the normal voltage for Lithium-Ion battery cell that is typically used in battery-powered devices, is chosen.

Keywords: dc-dc converter, inductors, efficiency, CMOS 0.35 µm technology

1. INTRODUCTION

With development of new technologies in the field of microelectronics is increasing the use of integrated circuits (IC) with large and very large scale of integration (LSI and VLSI), because the schematics became much more sophisticated. Physical sizes of the integrated components go down. This lead to decreasing of the breakdown voltages of the advanced CMOS processes.

The portable electronic devices have stringent requirements for longer battery life and system run-time. To decrease the energy losses is necessary subsystems to operate at its optimum supply voltages. The most effective way to reduce the power dissipation is high efficient dc-dc converter. The price of the system can be minimized with integration of as many blocks as possible on a single chip.

The switch-mode dc-dc converters have possibilities to indicate high efficiency results. Integration of the whole converter including the filter's components is necessary to make the system costly. This faces mainly technological problems, because the large value of the passive filter components will occupy huge silicon area. For decreasing of size of the output capacitor and inductor high switching frequency f_s is needed.

The CMOS the technology is suitable for low power, low voltage applications [1]. It allows control circuitry with extremely low power consumption and low-drop power devices to be integrated in the standard process. The big disadvantage of the available monolithic inductors in 0.35-µm CMOS technology is their low quality factor Q [2].

This paper presents the performance investigation of switch-mode buck and zero-current switching (ZCS) resonant-switch dc-dc converters, using on-chip and off-chip filter's inductors. In Section 2 are shown simulated characteristics of available standard monolithic inductors of AMS CMOS 0.35 µm process. The received results for two types of the analyzed step-down dc-dc converters are presented in Section 3.

The CADENCE design tools are used for the optimization of the mention above circuit's architectures.

2. INVESTIGATIONS OF AVAILABLE MONOLITHIC INDUCTORS OF AMS CMOS 0.35 μ**M PROCESS**

The basic circuit of step-down (buck) dc-dc converter is shown in Fig. 1. The passive filter components, which are inductor L_f and capacitor C_f, have very important function. They form the corner frequency f_c of low-pass filter, which has to eliminate the switching frequency ripple f_s in the output voltage V_{OUT}. For this purpose f_c has to be much lower than the switching frequency f_s.

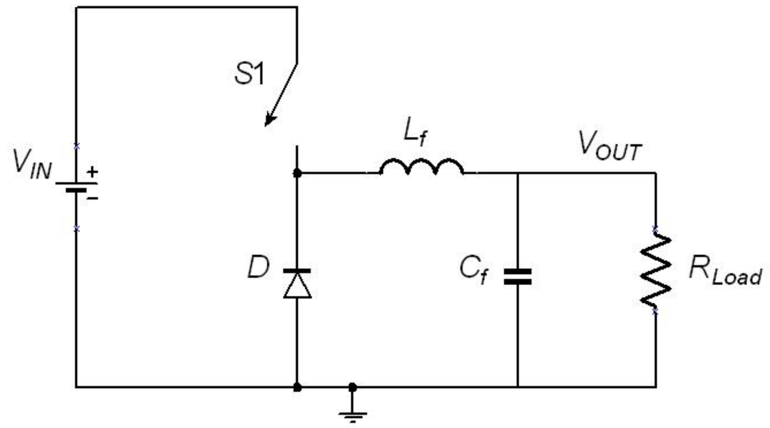


Fig. 1 Buck converter.

The price of the converter can be decreased with integration of passive components. To be minimized their values and sizes high switching frequency f_s is needed.

One of the main important parameters of the converters is efficiency η. It serves as a reference for estimation of these types of circuits. The output filter components, is good to have high quality factors in order not to decrease the overall efficiency η.

The monolithic inductors occupy large silicon area. They have lower Q factor compare to the capacitors. The investigation of the inductors characteristics is very important for dc-dc converter design [3].

Table1

	Inductors parameter			
	Q_{max}	**$f_{Q\ max}$, [GHz]**	**L at $f_{Q\ max}$, [nH]**	**f_{max}, [GHz]**
SP014S300D	6.7	3.2	1.3	24
SP020S180D	5.7	4.4	2	30
SP026S200D	5.5	3.9	2.7	16
SP037S180D	4.98	4.36	4.16	14
SP047S180D	4.7	3.4	5.2	12
SP050S155D	4.3	4	6	13
SP090S155D	3.55	3.2	10.6	9

The properties of available monolithic inductors of AMS CMOS 0.35 μm process are simulated with CADENCE design tools. The investigated parameters shown in

Table 1 are: Q_{max}, f_{Qmax}, L at f_{Qmax} and f_{max},

where Q_{max} is maximum quality factor of the inductor;

f_{Qmax} is frequency at which Q_{max} is appeared;

L at f_{Qmax} is the value of inductor at f_{Qmax};

f_{max} is the maximum frequency at which the simulated components are turned into capacitors.

Simulated characteristics for spiral monolithic inductor with name *SP090S155D* are shown in Fig. 2. The nomenclature *SP090S155D* means: P – square; 090 - 9 nH (nominal port 1 drive inductance multiplied by 10 in nH); S – single structure; 155 - 155x155 μm^2; D – 4 metal process. The maximum Q factor received at 3.2 GHz is equal to 3.55. The inductor value at this frequency is 10.6 nH.

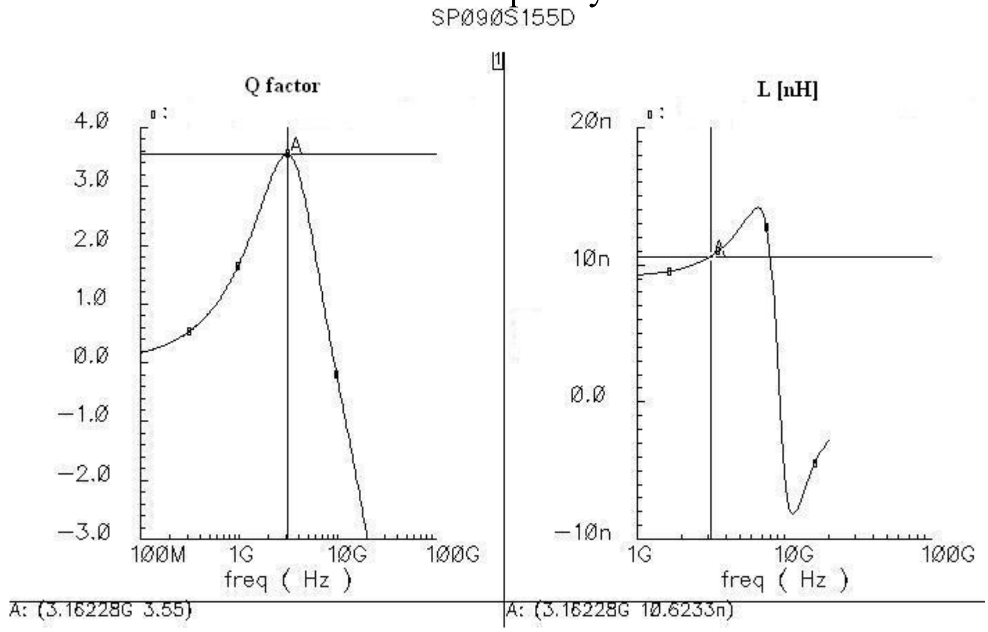
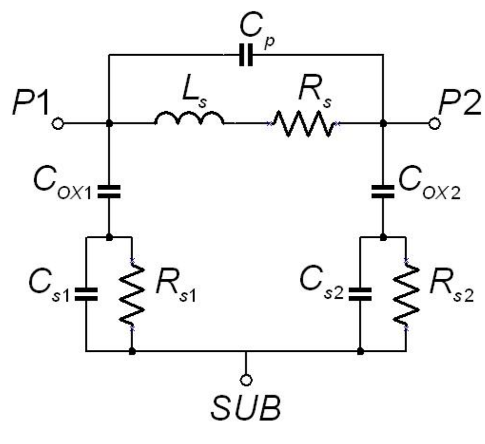


Fig. 2 Frequency response of Q factor and L for monolithic inductor *SP014S300D*.

As can be seen from Table 1 monolithic inductor of AMS CMOS 0.35 μm process have very low *Q* factor. The inductor's model is shown in Fig. 3. The layout of the standard monolithic inductor *SP090S155D* is shown in Fig. 4.



L_s – series inductance
R_s – series resistance
C_p – parallel capacitance
$C_{OX1/2}$ – oxide capacitance
$C_{s1/2}$ – substrate capacitance
$R_{s1/2}$ – substrate resistance

Fig. 3 Inductor's model..

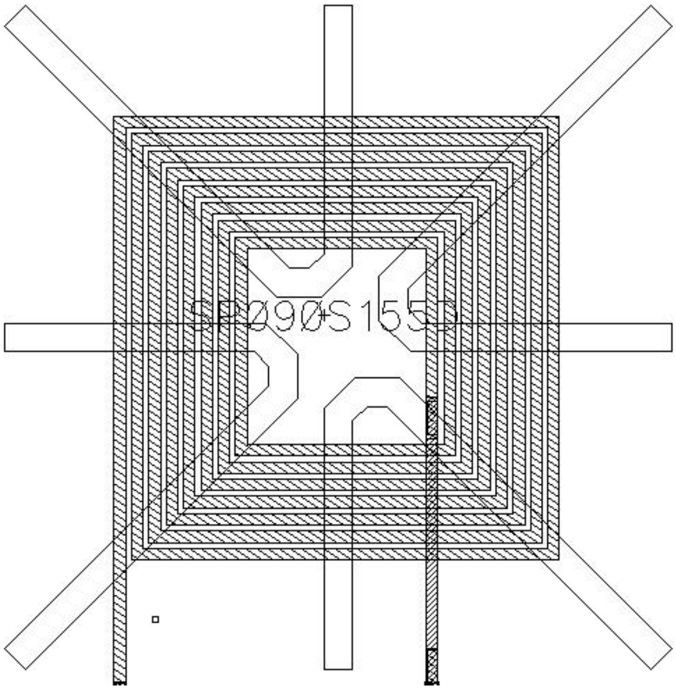


Fig. 4 Layout of the standard monolithic inductor *SP090S155D*.

3. ANALYSIS OF INDUCTORS INFLUENCE OVER THE BEHAVIOR OF STEP-DOWN DC-DC CONVERTERS

3.1 Investigations of switch-mode buck dc-dc converter

The simulated circuit of buck dc-dc converter is illustrated in Fig. 5. The diode from Fig. 1 is replaced by switch in order to be decreased the power losses [4]. The two transistors *M1* and *M2* are synchronously regulated. The input voltage V_{IN} is 3.6 V and the output voltage V_{OUT} is regulated to be 1.2 V.

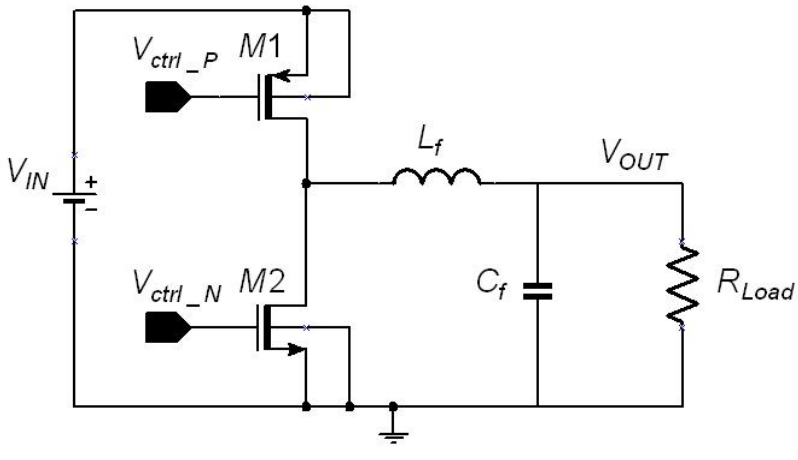


Fig. 5 Simulated buck dc-dc converter circuit.

In Fig. 6 are illustrated simulated results of buck converter efficiency η as function of filter inductor L_f at different load currents. The value and respectively the size of the filter inductor L is reverse proportional to the inductor current ripple ΔI_L, i.e. smaller inductor can be used if bigger ripples are allowed. The preferred value of

ΔI_L depends on the inductor size and efficiency requirements of the converter applications [5].

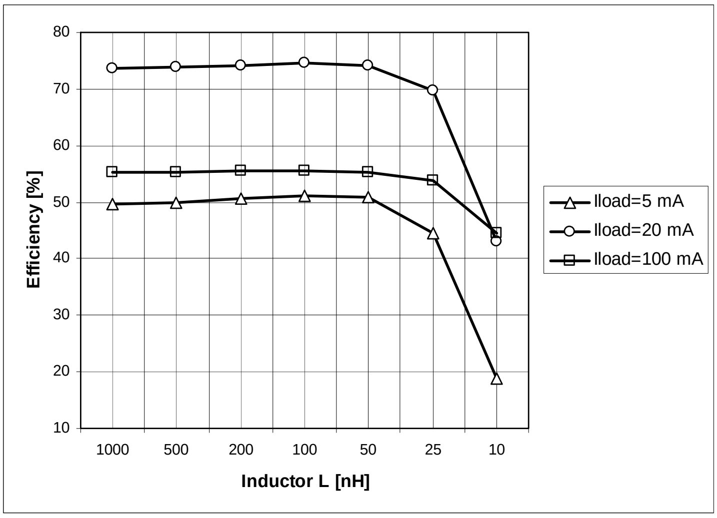


Fig. 6 Efficiency as a function of L_f.

DC-DC converter's efficiency comparison when off-chip and on-chip filter's inductors with equal values are used is shown in Fig. 7. As can be seen from the picture, integrated inductors reduce the efficiency η. For the case illustrated in Fig. 7, decreasing is about 15 %.

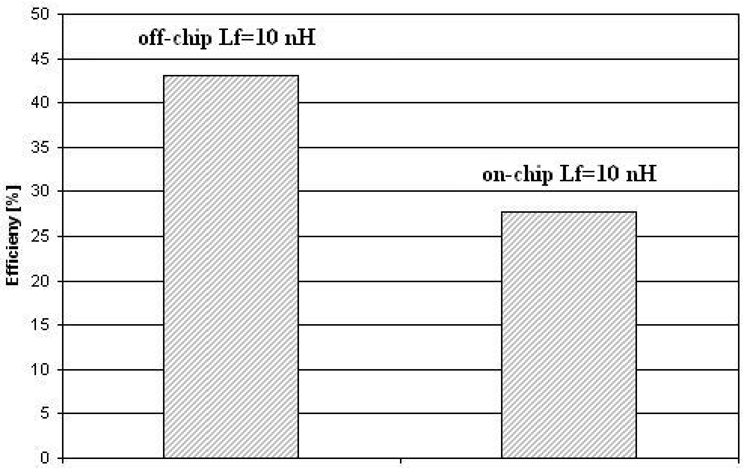


Fig. 7 Received simulated results of buck converter efficiency when off-chip and on-chip filter's inductors are used.

3.2 Investigations of ZCS resonant-switch dc-dc converters

The investigated circuit of ZCS resonant-switch dc-dc converter is illustrated in Fig.8. The input and output voltage are chosen to be the same like in Section 3.1. The simulated efficiency η, when off-chip and on-chip filter inductors are used, is respectively 75.7 [%] and 35 [%]. The received results are shown graphically in Fig.9. Significant reduction of converter's efficiency can be observed.

Considering the results from Section 3.1 and 3.2 can be said that available monolithic inductors can not satisfied requirements for dc-dc converters. Their big disadvantage compare to the off-chip components is low Q factor.

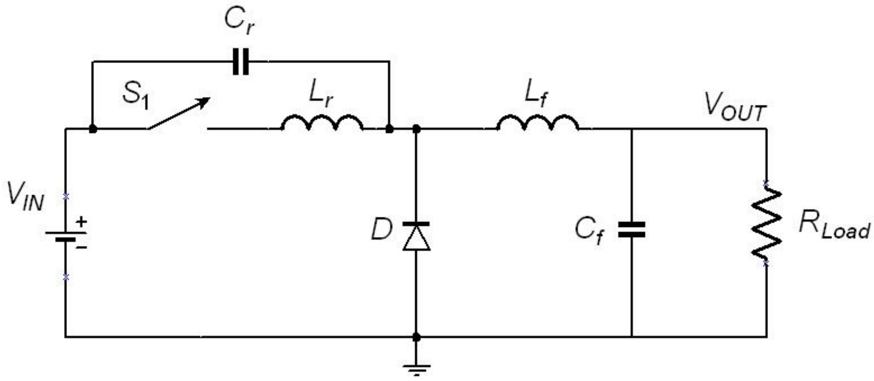


Fig. 8 Simulated ZCS resonant-switch dc-dc converter circuit.

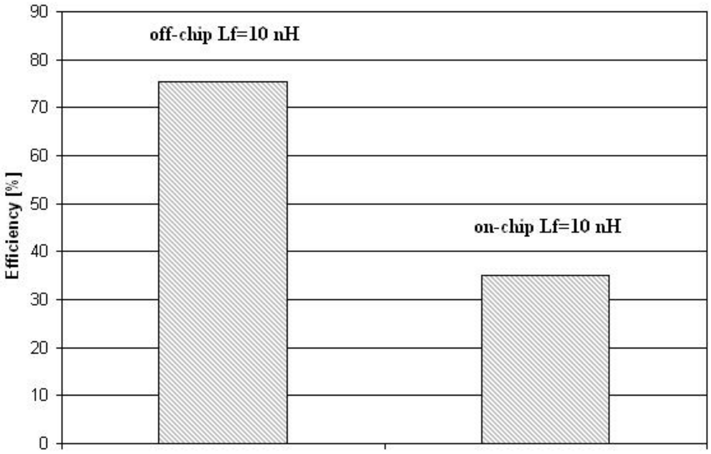


Fig. 9 Received simulated results.

4. CONCLUSIONS

The characteristics of the available standard monolithic inductors of AMS CMOS 0.35 µm process are investigated. Two types of step-down dc-dc converters are considered. The influence of inductor's parameter over the efficiency of these circuits is evaluated.

5. ACKNOWLEDGMENTS

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