# THE INFLUENCE OF LAYOUT ON BASIC PARAMETERS OF INTEGRATED PASSIVE DEVICES

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*This paper intends to point out some differences and consequences of using different layout geometry, shape and form of the passive devices. The research is made from the point of view of the layout influence on the basic parameters of the integrated passive devices. Resistors, inductors, and capacitors with structures created on different physical layers with various layer material properties are also studied, analyzed and presented.*

**Keywords:** resistors, capacitors, inductors, RF, layout influence, research

## 1. INTRODUCTION

In modern submicron technologies, where can be fabricated high performance active devices, the importance of passive devices is often underestimated. The poor parameters and characteristics of passive devices degrade the excellent high-speed properties of active devices in RF and microwave integrated circuits. In addition, while active devices are continually shrinking and occupying less and less chip area passive devices still remain large and determine overall size and cost of the whole integrated circuit. Therefore, passive devices play a critical part in modern integrated circuit design.

Although, resistors and capacitors seems to be simple devices, in practical design and at high frequencies in particular, detailed structure, layout, technology and material properties of the passive devices must be taken into consideration, as well as their surroundings. Additionally, the use of passive devices such as inductors is traditionally most problematic and difficult to realize in integrated circuits.

On the other hand, the advantages of integrating RF circuits with active and passive devices are compelling. The fewer the external components, the smaller is the size of the entire circuit or system and perhaps the smaller the power consumptions. Furthermore, integration enhances the reliability of the end product as it minimizes the number of external connections that require soldering. Thus, it is necessary to study carefully the limitation of passive devices and their parasitics, respectively.

The main goal of this paper is to investigate the layout influence on basic parameters of integrated passive devices for two technologies, CMOS and SiGe BiCMOS 0.35μm, in order to derive a set of rules and guidance for their design, especially for high frequency applications. In order to accomplish that computer-aided system Cadence, Spectre circuit simulator and Diva verification tools are used.

## 2. RESISTORS

Resistors provide specific and controlled amounts of electrical resistance. They are useful in a variety of applications, ranging from current limiting to voltage

division. Analog circuits usually include many resistors, so it is fortunate that they are relatively easy to integrate. Most processes offer a choice of several different resistor materials. In case of AMS 0.35μm Si CMOS and AMS 0.35μm SiGe BiCMOS technologies, diffusion, polysilicon and high resistivity polysilicon resistors are available. Some are better suited to fabricating high-value resistors and others to fabricating low-value ones. The choice of resistor materials can have tremendous impact on circuit performance, so substitutions should not be mate without careful consideration on the consequences [1], [2].

Resistors with different values of width (W=1μm, 2μm, 3μm, 5μm, 10μm, 20μm) and length (L=10μm, 30μm, 60μm), and thus different resistance are investigated. In table 1 are compared and summarized the results for resistor with W/L=2μm/60μm using different resistor materials – p-diffusion and polysilicon layers with different implantation (i.e. different sheet resistance). It is evident, that polysilicon resistors are superior in comparison with the others. Resistors created on first polysilicon layer are more precise and have better quality factors in wide frequency range than the one created using high resistivity polysilicon layers.

Table 1. Resistance and quality factor for resistors created using different materials

| **Resistor material** | **R, Ω** | **$R_{P1}$@1GHz, Ω** | **$Q_{P1}$@1GHz** | **$R_{P1}$@6GHz, Ω** | **$Q_{P1}$@6GHz** |
|---|---|---|---|---|---|
| 1st polysilicon | 1714 | 1711.83 | 34.33 | 1665.29 | 5.92 |
| High resistivity polysilicon | 4000 | 73822.2 | 1.13 | 1836.44 | 0.35 |
| 2nd polysilicon | 7200 | 7083.23 | 7.38 | 4992 | 1.84 |
| Diffusion | 3714 | 280.91 | 0.289 | 11.9767 | 0.07 |

In the table above R is extracted resistance of the structure. $R_{P1}$ and $Q_{P1}$ are derived resistance and quality factor from two-port Z and Y-parameters for one port driven circuit. In the case of a resistor the quality factor Q is the ratio of the real to the imaginary part of the impedance. The loss of resistance is the signal absorbed by the parallel reactance.

In table 2 are presented the results for folded (meander) resistor, employing three rectangular and 45° turns (called bands) using different spacing between turns S. First polysilicon layer is used, because it allows achieving better Q-factor and work at higher frequencies. From the presented results given in comparison with straight unfolded resistor with W/L=2μm/60μm is clear that unfolded resistors have highest Q-factor. On the other hand if the resistor is too long it is better to use 45˚ turns minimal spacing.

Table 2. Extracted resistance and length, and simulated resistance and Q-factor for resistors with 45˚ and 90˚ turns and different spacing between turns

| **Bands angle** | **L, μm** | **S, μm** | **R, kΩ** | **$R_{P1}$@1GHz, Ω** | **$R_{P1}$@6GHz, Ω** | **$Q_{P1}$@1GHz** | **$Q_{P1}$@6GHz** |
|---|---|---|---|---|---|---|---|
| straight | 60 | - | 1.714 | 1711.83 | 1665.29 | 34.33 | 5.92 |
| 45 | 60.04 | 0. 5 | 1.715 | 1712.99 | 1628.22 | 26.61 | 4.47 |
| 45 | 61.54 | 1 | 1.758 | 1755.73 | 1663.07 | 26.27 | 4.3 |
| 45 | 64.54 | 2 | 1.844 | 1841.63 | 1739.42 | 26.83 | 4.41 |
| 90 | 60.1 | 0.5 | 1.717 | 1714.4 | 1622.56 | 26.22 | 4.15 |
| 90 | 61.6 | 1 | 1.76 | 1756.96 | 1655.9 | 25.46 | 3.90 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 90 | 64.6 | 2 | 1.846 | 1842.6 | 1731.28 | 24.55 | 3.90 |

In table 3 are shown the results for meander polysilicon resistor with 45° turns, distance between turns S=0.5, and different number of bends. The result are also compared with straight unfolded resistor with W/L=2μm/60μm.

Table 3. Comparison of resistor length, resistance and Q-factor for polysilicon resistor with different number of bends

| **Number of bends** | **L, μm** | **R, Ω** | **$R_{P1}$@1GHz, Ω** | **$R_{P1}$@6GHz, Ω** | **$Q_{P1}$@1GHz** | **$Q_{P1}$@6GHz** |
|---|---|---|---|---|---|---|
| none | 60 | 1714 | 1711.83 | 1665.29 | 34.33 | 5.92 |
| 1 | 59.98 | 1714 | 1687.55 | 1178 | 9.06546 | 1.84959 |
| 2 | 59.96 | 1713 | 1676.46 | 1030.38 | 7.05565 | 1.36882 |
| 3 | 60.04 | 1715 | 1691.72 | 1230.13 | 9.99497 | 1.95001 |

In table 4 are depicted the results for the resistance, absolute (Δ) and relative deviations (δ) from the nominal value of one polysilicon resistor divided to several segments with matching in comparison with the same value folded resistor with three bends and 45°-angle. Using smaller and matched segments reduce the error caused by non uniform current distribution, although the accuracy improvement is small. Nevertheless they are preferred when resistors must operate at higher frequencies.

Table 4. Results from comparison of one polysilicon matched resistor versus the same value 3 bends and 45°-angle folded resistor

| | **f, GHz** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| 45°-angle | R, Ω | 2234.84 | 2190.24 | 2131.71 | 2050.87 | 1961.67 | 1875.26 |
| | Δ, Ω | 16.73 | 61.33 | 119.86 | 200.7 | 289.9 | 376.31 |
| | δ, % | 0.743037 | 2.723877 | 5.323397 | 8.91378 | 12.87546 | 16.71323 |
| matched | R, Ω | 2243.21 | 2204.18 | 2156.79 | 2089.9 | 2009.06 | 1919.86 |
| | Δ, Ω | 8.36 | 47.39 | 94.78 | 161.67 | 242.51 | 331.71 |
| | δ, % | 0.371296 | 2.104754 | 4.209507 | 7.180323 | 10.77071 | 14.73239 |

Comparison between simulated, extracted and measurement results is also made. The result for polysilicon resistor with W/L=2μm/60μm is shown in table 5.

Table 5. Simulated, extracted and measured results for the resistance of polysilicon resistor in frequency range from 1 to 6 GHz and absolute and relative deviations from the measured value

| **f, GHz** | **Simulated** | | | **Extracted** | | | **Measured** |
|---|---|---|---|---|---|---|---|
| | R, Ω | Δ, Ω | δ, % | R, Ω | Δ, Ω | δ, % | R, Ω |
| 1 | 1711.09 | 73.24 | 4.104622 | 1711.09 | 73.24 | 4.104622 | 1784.33 |
| 2 | 1704.99 | 74.83 | 4.204358 | 1701.82 | 78 | 4.382466 | 1779.82 |
| 3 | 1694.11 | 79.61 | 4.488307 | 1689.32 | 84.4 | 4.758361 | 1773.72 |
| 4 | 1675.28 | 97.12 | 5.479576 | 1673.68 | 98.72 | 5.569849 | 1772.4 |
| 5 | 1658.01 | 106.69 | 6.045787 | 1648.47 | 116.23 | 6.586389 | 1764.7 |
| 6 | 1632.8 | 121.02 | 6.900366 | 1623.25 | 130.57 | 7.444892 | 1753.82 |

## 3. CAPACITORS

Capacitors are class of passive elements useful for coupling AC signals and for constructing timing and phase shift networks. They are relatively bulky devices that store energy in electrostatic fields. Analog circuits usually include at least one capacitor. Therefore, most processes offer different type of capacitors. The most commonly used one is the polysilicon capacitor. Two different polysilicon layers are

used for its plates [1], [2]. It is available in AMS 0.35μm Si CMOS and AMS 0.35μm SiGe BiCMOS technologies, along with Metal-Insulator-Metal (MIM) and Metal-Oxide-Semiconductor (MOS) capacitors. For MIM capacitor the two plates are formed using different metal layers, and for MOS accumulation mode capacitor is implemented.

Capacitors with different form and values of width and length (10μm, 15μm, 23.9μm, 33.9μm, etc), and thus, different capacitance (C = 100fF÷5pF) are investigated. Analysis of the received results points out that square geometry is better than the rectangular one. In table 6 are summarized and compared simulated and extracted results for some square polysilicon capacitors. C and Q are derived from two-port Y-parameters for two-port driven circuit.

Table 6. Comparison of simulated and extracted results for capacitance, resistance and quality factor of polysilicon capacitor with different sizes

| Capacitor | f, GHz | R, Ohm | | C, fF | | Q | |
|---|---|---|---|---|---|---|---|
| | | sim | ext | sim | ext | sim | ext |
| W=L=10 μm | 1 | 17.27 | 16.954 | 84.695 | 85.480 | 108.835 | 109.844 |
| | 2 | 17.27 | 16.955 | 84.950 | 85.735 | 54.241 | 54.743 |
| | 3 | 17.27 | 16.957 | 85.380 | 86.164 | 35.980 | 36.311 |
| | 4 | 17.27 | 16.959 | 85.989 | 86.773 | 26.793 | 27.038 |
| | 5 | 17.27 | 16.962 | 86.784 | 87.567 | 21.238 | 21.431 |
| | 6 | 17.27 | 16.965 | 87.777 | 88.559 | 17.498 | 17.655 |
| W=L=15 μm | 1G | 13.489 | 13.343 | 193.154 | 194.205 | 61.099 | 61.431 |
| | 2G | 13.489 | 13.344 | 194.489 | 195.539 | 30.333 | 30.497 |
| | 3G | 13.489 | 13.346 | 196.755 | 197.804 | 19.990 | 20.097 |
| | 4G | 13.489 | 13.348 | 200.018 | 201.064 | 14.747 | 14.825 |
| | 5G | 13.489 | 13.351 | 204.375 | 205.418 | 11.546 | 11.606 |
| | 6G | 13.489 | 13.355 | 209.966 | 211.005 | 9.3658 | 9.413 |
| W=L=23.9 μm | 1G | 11.685 | 11.610 | 490.792 | 492.377 | 27.758 | 27.848 |
| | 2G | 11.685 | 11.611 | 499.501 | 501.080 | 13.634 | 13.677 |
| | 3G | 11.685 | 11.614 | 514.728 | 516.294 | 8.821 | 8.848 |
| | 4G | 11.685 | 11.616 | 537.671 | 539.218 | 6.333 | 6.352 |
| | 5G | 11.685 | 11.620 | 570.360 | 571.878 | 4.776 | 4.790 |
| | 6G | 11.685 | 11.625 | 616.142 | 617.612 | 3.684 | 3.694 |

The parallel between simulated, extracted and measured results for the capacitance and the quality factor of capacitor with W=L=33.9 μm is given in table 7. The results, received after extraction, are very close to the corresponding measurement values.

Table 7. Simulated, extracted and measured results for capacitance and Q-factor of polysilicon capacitor

| f, GHz | Simulated | | Extracted | | Measured | |
|---|---|---|---|---|---|---|
| | C, pF | Q | C, pF | Q | C, pF | Q |
| 1 | 0.999048 | 39.8773 | 0.945714 | 98.0109 | 0.945714 | 99.0283 |
| 2 | 1.03714 | 23.5704 | 0.945714 | 67.9584 | 0.945714 | 69.4875 |
| 3 | 1.10571 | 9.38984 | 0.953333 | 44.0827 | 0. 941905 | 47.1438 |
| 4 | 1.22 | 2.85765 | 0.953333 | 32.9618 | 0.945714 | 33.4764 |
| 5 | 1.38381 | 2.45068 | 0.957143 | 26.9412 | 0.945714 | 26.9368 |
| 6 | 1.69619 | 2.55095 | 0.960952 | 22.4498 | 0.949524 | 23.9804 |

## 4. INDUCTORS

The rapid development of modern communication systems demands a higher

level integration in the design of radio frequency integrated circuits (RFICs). In many cases, these designs cannot be realized without using the integrated spiral inductors. Thus, knowledge to realize high performance spiral inductors with desired inductance, Q-factor and self-resonance frequency (SRF) is very important. Recently, great efforts have been devoted to the modeling, optimization and design of the spiral inductors [3].

A thorough study on the performance trends of different spiral inductors is made in this paper. Inductors with various outer diameter $D_{out}$=140÷300μm, metal width W=5÷20μm, spacing between adjacent turns S=2÷10μm and number of turns N=1.75÷10 are examined. Some of the results are presented in table 8. In the tables below L is spiral inductance, $R_S$ is its series resistance and Q is the quality factor for one port drive operation.

Table 8. L, $R_S$ and Q for inductors with different geometry

| **Name and geometry parameters** | **f, GHz** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| **SQ1** | **L, nH** | 2.075 | 2.091 | 2.115 | 2.15 | 2.196 | 2.256 |
| $D_{out}$=250 μm, W=20 μm, S=3 μm, | **$R_S$, Ω** | 3.19 | 3.667 | 4.497 | 5.726 | 7.429 | 9.718 |
| N=1.75 | **Q** | 4.087 | 7.164 | 8.866 | 9.437 | 9.288 | 8.751 |
| **SQ2** | **L, nH** | 3.029 | 3.118 | 3.245 | 3.409 | 3.62 | 3.893 |
| $D_{out}$=250 μm, W=10 μm, S=3 μm, | **$R_S$, Ω** | 4.097 | 4.853 | 6.845 | 10.649 | 17.026 | 27.314 |
| N=1.75 | **Q** | 4.646 | 8.075 | 8.937 | 8.047 | 6.68 | 5.373 |
| **SQ3** | **L, nH** | 2.313 | 2.38 | 2.469 | 2.589 | 2.751 | 2.972 |
| $D_{out}$=250 μm, W=20 μm, S=3 μm, | **$R_S$, Ω** | 6.258 | 6.8 | 7.905 | 9.637 | 12.11 | 15.51 |
| N=2.75 | **Q** | 3.272 | 6.096 | 7.99 | 8.93 | 9.123 | 8.835 |
| **SQ4** | **L, nH** | 3.26 | 3.299 | 3.352 | 3.424 | 3.516 | 3.634 |
| $D_{out}$=250 μm, W=10 μm, S=3 μm, | **$R_S$, Ω** | 2.41 | 3.198 | 4.996 | 8.101 | 13.096 | 21.11 |
| N=2.75 | **Q** | 6.04 | 9.351 | 9.315 | 8.031 | 6.6 | 5.31 |
| **SQ5** | **L, nH** | 3.611 | 3.742 | 3.94 | 4.209 | 4.569 | 5.057 |
| $D_{out}$=250 μm, W=10 μm, S=10 μm, | **$R_S$, Ω** | 4.387 | 5.323 | 7.922 | 13.22 | 22.834 | 39.916 |
| N=2.75 | **Q** | 5.172 | 8.834 | 9.376 | 7.999 | 6.286 | 4.776 |

The results given in table 8 present the trends that change with geometrical parameters. For example, with a fixed outer-dimension, $Q_{max}$ is a decreasing function of spacing. For inductors with fixed outer-dimension (or with simultaneously varied inner- and outer-dimensions), increasing track width results in a higher $Q_{max}$, but a decreased L. $Q_{max}$ is decreasing function of turn numbers, while L is an increasing function of turn numbers.

In addition, planar spiral inductors created using different metal layer and different shapes are also investigated. In table 9 are given the results from the comparison of three square spiral inductors with inner diameter $D_{in}$=150μm, W=20μm, S=2μm and N=2, created on different metal layers. While in table 10 are compared inductors with different shape – square and octagonal. It is evident that with the increase of the distance from substrate (e.g. using higher metal layer) improves the quality factor of the inductors, due to lower substrate parasitics. From table 10, it is also clear that with the use of octagonal inductors higher inductance values, lower series resistance and better quality factor can be achieved.

Table 9. Comparison of square spiral inductors created using different metal layers

| f, GHz | SQ1 (metal4) | | | SQ2 (metal3) | | | SQ3 (metal2) | | |
|---|---|---|---|---|---|---|---|---|---|
| | L, nH | $R_S$, Ω | Q | L, nH | $R_S$, Ω | Q | L, nH | $R_S$, Ω | Q |
| 1 | 1.42 | 1.643 | 5.32 | 1.493 | 6.156 | 1.493 | 1.494 | 6.169 | 1.486 |
| 2 | 1.41 | 2.095 | 7.699 | 1.493 | 6.759 | 2.618 | 1.495 | 6.815 | 2.577 |
| 3 | 1.412 | 2.49 | 8.79 | 1.495 | 7.463 | 3.371 | 1.496 | 7.591 | 3.269 |
| 4 | 1.418 | 2.876 | 9.12 | 1.5 | 8.228 | 3.83 | 1.502 | 8.453 | 3.657 |
| 5 | 1.426 | 3.27 | 8.99 | 1.509 | 9.051 | 4.069 | 1.511 | 9.402 | 3.826 |
| 6 | 1.437 | 3.678 | 8.64 | 1.523 | 9.946 | 4.145 | 1.525 | 10.46 | 3.828 |

Utilization of thick metal layer in the given technology can increase the quality factor of the inductors. Thus, square spirals with Q-factor above 10 can be implemented.

Table 10. Comparison of square and octagonal spiral inductor and square spiral inductor created using thick metal layer

| f, GHz | 1 (octagonal) | | | 2 (square) | | | 3 (square thick metal) | | |
|---|---|---|---|---|---|---|---|---|---|
| | L, nH | $R_S$, Ω | Q | L, nH | $R_S$, Ω | Q | L, nH | $R_S$, Ω | Q |
| 1 | 2.83205 | 6.47771 | 0.25641 | 2.83205 | 8.13873 | 0.17094 | 3.00579 | 4.09949 | 0.5128 |
| 2 | 2.83205 | 6.73877 | 0.55556 | 2.83205 | 8.16742 | 0.59829 | 2.98842 | 4.11957 | 1.2821 |
| 3 | 2.84942 | 6.75885 | 1.53846 | 2.81467 | 8.18177 | 1.19658 | 3.00579 | 4.16547 | 2.6496 |
| 4 | 2.83205 | 6.7818 | 2.00855 | - | 8.21906 | 1.66667 | 2.98842 | | 3.4615 |
| 5 | 2.88417 | 6.33427 | 2.39316 | 2.83205 | 8.00103 | 2.17949 | 2.98842 | 4.19129 | 4.5299 |
| 6 | 2.88417 | 6.83344 | 2.94872 | 2.84942 | 8.25922 | 2.5641 | 3.02317 | 4.45235 | 5.1282 |

The effective series inductance L and quality factor Q are estimated for one port drive operation using Y-parameters and compared with measurement. The results are presented in table 11.

Table 11. Comparison of simulated and measured results for inductance and quality factor of a spiral inductor

| | f, GHz | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| **Simulation** | **L, nH** | 4.64463 | 4.81051 | 5.07354 | 5.46389 | 5.9588 | 6.6334 |
| | **Q** | 3.98864 | 6.54545 | 8.07955 | 7.69602 | 6.41761 | 4.93466 |
| **Measure-ment** | **L, nH** | 4.69703 | 4.82543 | 5.02859 | 5.42647 | 5.98134 | 6.6633 |
| | **Q** | 3.70739 | 6.62216 | 7.97727 | 8.02841 | 6.57102 | 4.9858 |

## 5. CONCLUSIONS

In this research were investigated the trends of integrated passive devices performance and electrical parameters variation influenced by different geometrical parameters and layout. These results can be a good guideline for practical design of passive components with application in RF integrated circuits.

## 6. REFERENCES

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