Fundamental Lumped Components at High Frequencies

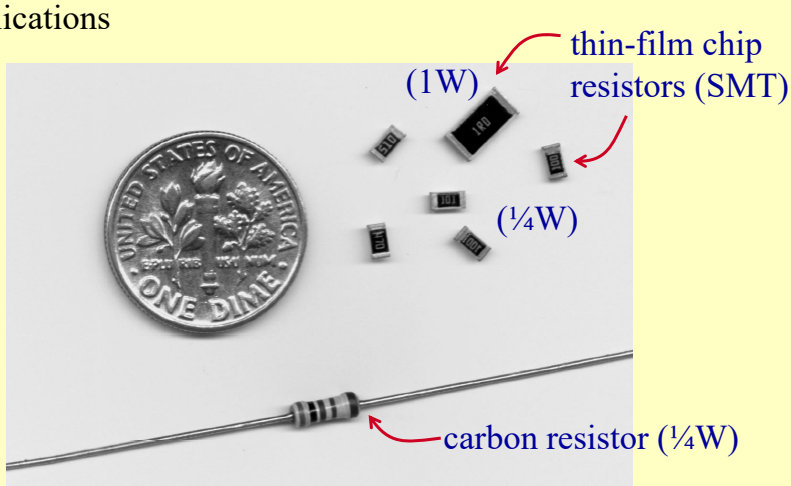
Dr. José Ernesto Rayas-Sánchez

Outline

- Lumped resistors
- Lumped capacitors
- Lumped inductors

Lumped Resistors

Thin-film chip resistors are used for RF and microwave applications



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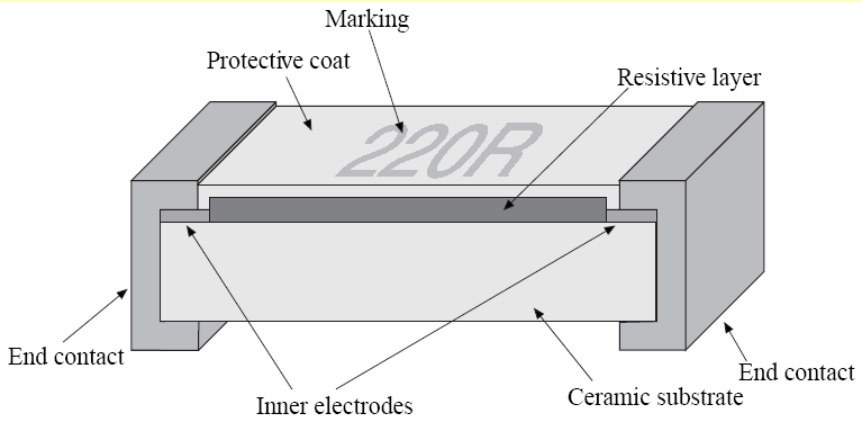
Lumped Resistors (cont.)

Typical thin-film chip resistor



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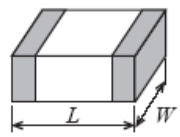
Lumped Resistors (cont.)

Standard sizes for thin-film chip resistors



Geometry	Size Code	Length L, mils	Width W, mils
	0402	40	20
	0603	60	30
	0805	80	50
	1206	120	60
	1218	120	180

Resistance value range: 10^{-1} - 10^{6} Ω

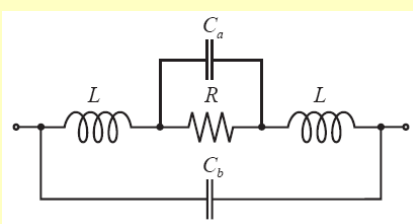
Typical tolerances: ±5% to ±0.01%

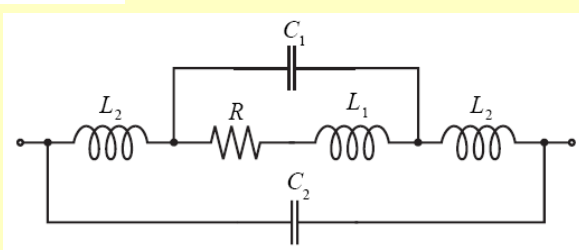
Power ranges: 0.25W to 1000W

(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)

Lumped Resistors (cont.)

Approximate equivalent circuits:

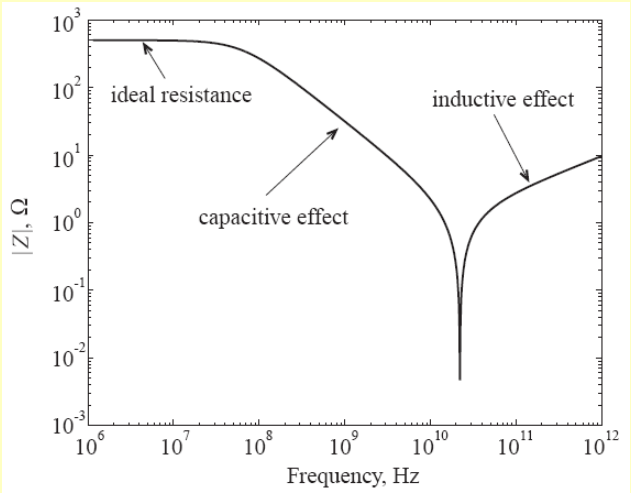




(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)

Lumped Resistors (cont.)

Typical behavior (500-Ω thin-film resistor)



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(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)

Practical Resistive Terminators

0603 chip

QSOP

BGA

Best to worst:

1) BGA
2) 0603 chip
3) QSOP
4) Axial leaded

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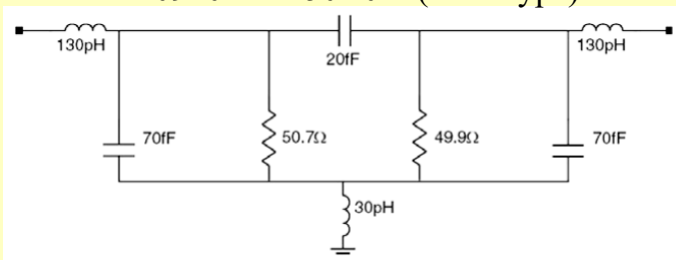
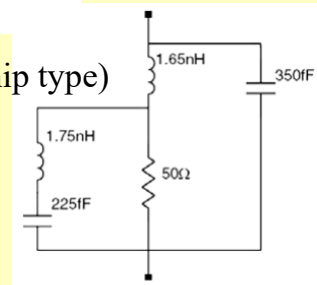
(J. Seams, High-Frequency Electronics, October 2005)

Practical Lumped Resistor Models

CHC-CC0910B-xx-50R0-x (BGA type)



PFC-W0603HF-xx-50R0-x (0603 chip type)



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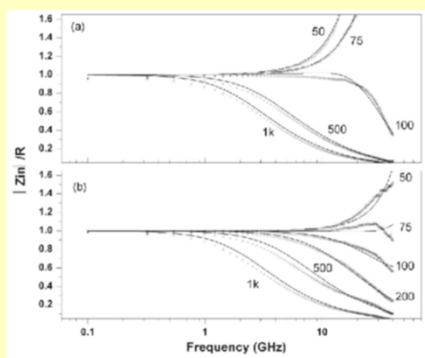
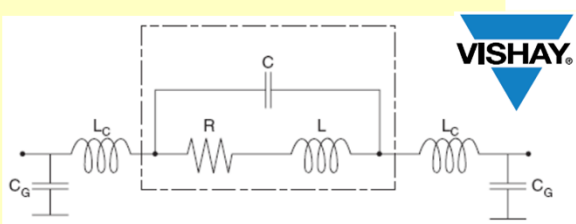
(J. Seams, High-Frequency Electronics, Oct. 2005) 9

Commercial Thin Film Chip Resistors

TABLE 1 - PARAMETERS FOR DIFFERENT CASE SIZES UTILIZED

CASE SIZE	LENGTH (inch/ mm)	WIDTH (inch/ mm)	RESISTOR AREA (inch^2/ mm^2)	MODEL INTERNAL COEFFICIENTS	
				C (pF)	L (nH)
0201	0.02/ 0.51	0.01/ 0.25	0.00004/ 0.02581	0.0206	1.73×10^{-5}
0402	0.04/ 1.02	0.02/ 0.51	0.000352/ 0.22710	0.0262	1.89×10^{-3}
0402 (wrap)	0.04/ 1.02	0.02/ 0.51	0.000352/ 0.22710	0.0392	0.1209
0603	0.064/ 1.626	0.032/ 0.813	0.000816/ 0.52645	0.0403	0.0267





VISHAY

C: internal shunt capacitance
L: internal inductance
R: resistance
L_C: external connection inductance
C_G: external capacitance to ground

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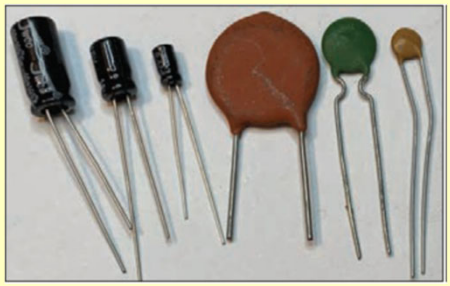
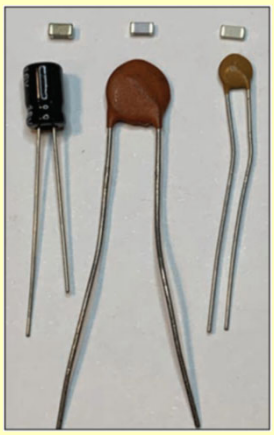
(Vishay Intertechnology, 2009) 10

Lumped Capacitors

Electrolytic and ceramic disc capacitors are rarely used for RF and microwave applications due to their large parasitic effects



SMT (1206 package) *vs.* ceramic disc capacitors (corresponding values):



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(Bogatin, Smith and Sandler, 2020)

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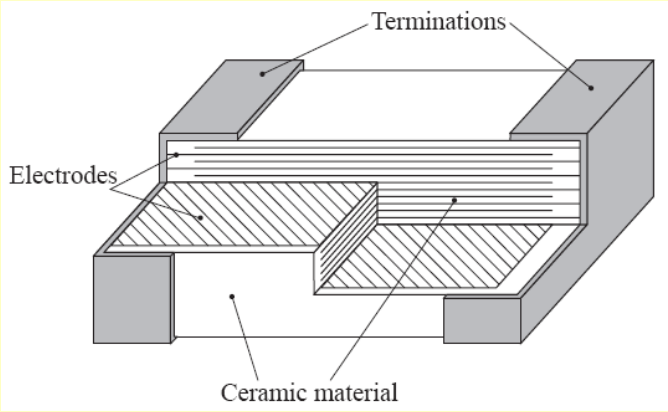
Lumped Capacitors (cont.)

SMT ceramic capacitors are the most common kind of lumped capacitor for RF and microwave applications



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(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)

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Lumped Capacitors (cont.)

- Capacitance value range: 0.1pF – 1μF
- Typical tolerances: ±2% to ±50%
- Operating voltage range: 16V – 63V
- Standard sizes: from 15mil×15mil to 400mil×425mil

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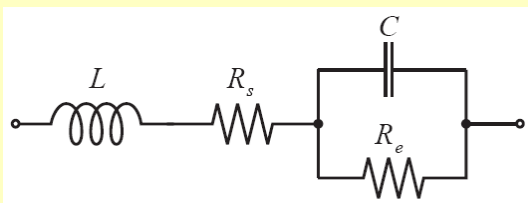
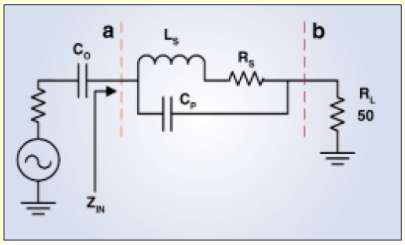
Lumped Capacitors (cont.)

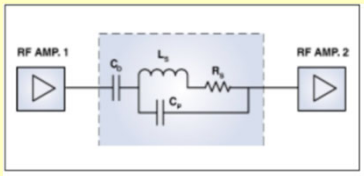
Approximate equivalent circuit models



(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)



▲ Figure 5. Nominal capacitor C_0 with parasitic elements.



▲ Figure 1. Interstage coupling, 50 MHz to 3.6 GHz.

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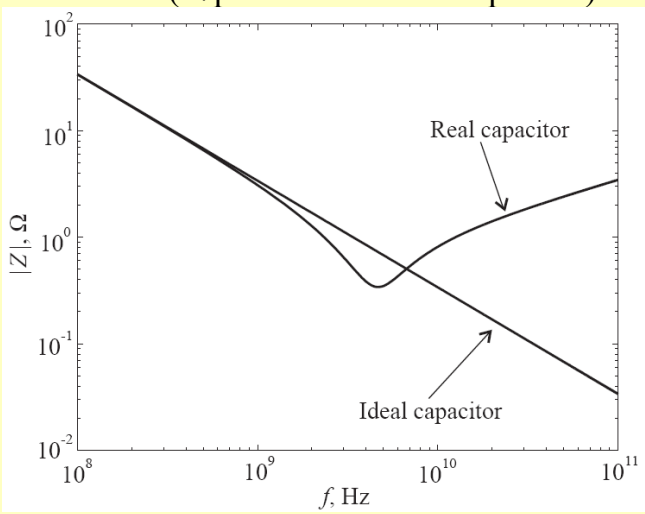
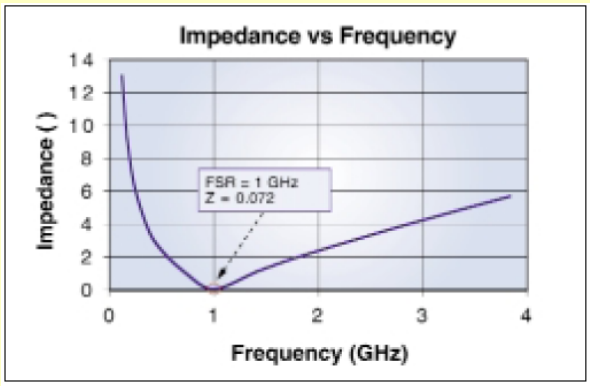
Lumped Capacitors (cont.)

Typical behavior (47pF SMT ceramic capacitor)



(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)

Lumped Capacitors (cont.)



▲ **Figure 7. Impedance versus frequency for an ATC100A101 (100 pF).**

(R. Fiore, Microwave and Wireless Applications, May 2001)

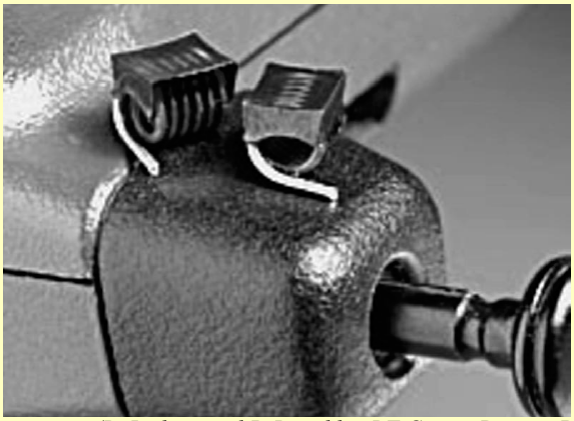
Lumped Inductors

The most common implementation of inductors in RF and microwave applications are:

- Wire-wound SMT inductors
- Flat spiral inductors

Lumped Inductors (cont.)

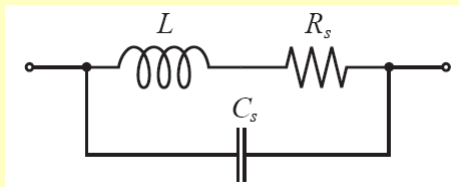
- Wire-wound SMT inductors:
  - Inductance value range: 1nH – 1mH
  - Standard sizes: from 30mil×60mil to 180mil×120mil



(R. Ludwig and P. Bretchko, RF Circuit Design, Prentice Hall, 2000)

Lumped Inductors (cont.)

Simplified model for wire-wound SMT inductors



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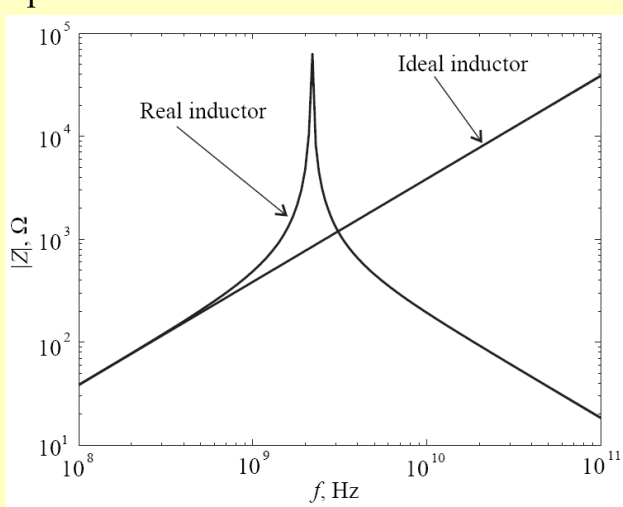
Lumped Inductors (cont.)

Typical performance of SMT inductors



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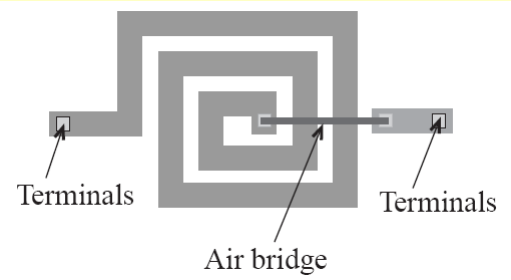
Lumped Inductors (cont.)

- Flat spiral inductors
  - Can be built on PCBs (FR4 substrate) or within an integrated circuit (silicon substrate)
  - Inductance value range: 0.5nH – 500nH
  - Standard sizes: smaller than 2mil×2mil



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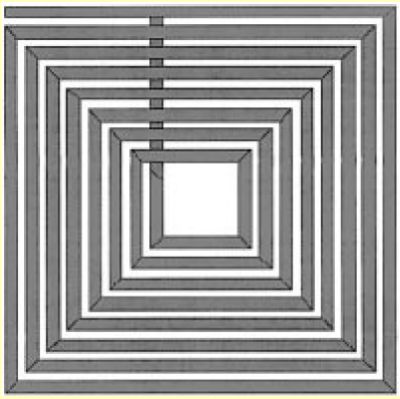
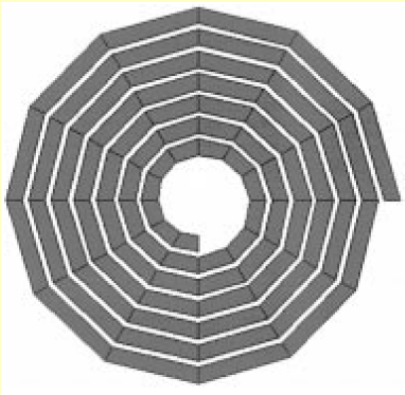
Lumped Inductors (cont.)

Typical geometries for spiral inductors





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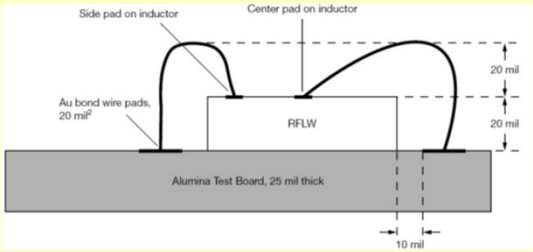
Commercial Spiral Inductors

(RFLW series)



RF CHARACTERISTICS - TYPICAL VALUES							
PART NUMBER	INDUCTANCE (nH)		DCR (Ω)	IN-CIRCUIT INDUCTANCE (4) (nH)	Q (UNITLESS)		SRF (GHz)
	250 MHz	1000 MHz			250 MHz	1000 MHz	
RFLW5N1800B	18	19	1.0	19	16	13	6
RFLW5N5200B	47	49	3.3	48	16	9	3.8
	52	56	3.6	53	17	9	3.5
RFLW5N8000B	80	87	4.5	82	18	7	2.4
RFLW5N1000A	100	125	5.4	102	17	5	1.9
RFLW5N1200A	120	156	7.7	122	18	4	1.7
RFLW5N1500A	150	220	9.3	152	18	3	1.5

Note
(4) Including the added inductance and resistance of typical bond wires at 250 MHz. See equivalent circuit section below.

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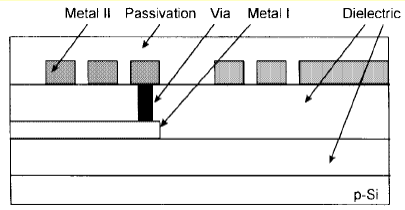
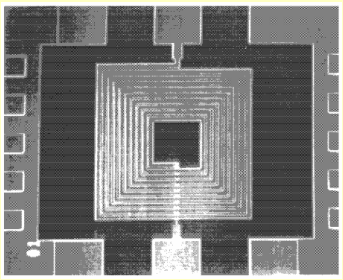
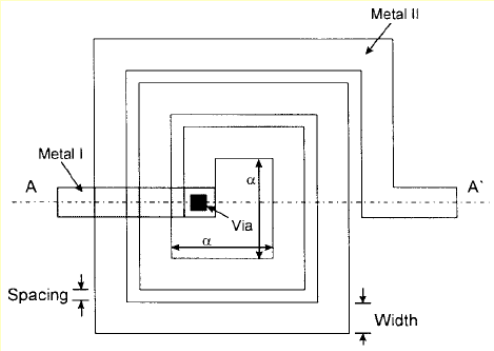
Lumped Spiral Inductors on Silicon

- Flat spiral inductors on silicon (CMOS technology)







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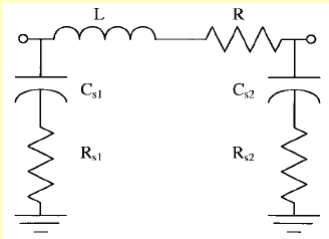
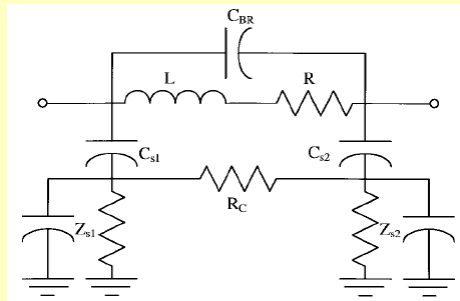
Lumped Spiral Inductors on Silicon (cont.)

Equivalent circuit models for flat spiral inductors on silicon





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(A. M. Niknejad, 1998)

Lumped Spiral Inductors on Silicon (cont.)

Circuit model for several CMOS spiral inductors obtained from curve fitting

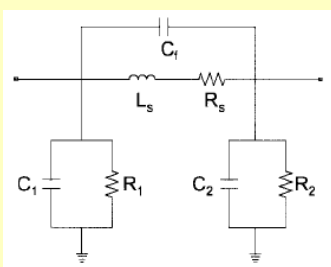

TABLE I
SUMMARY OF EXTRACTED EQUIVALENT CIRCUIT MODEL PARAMETERS FOR THE VARIOUS KINDS OF RECTANGULAR SPIRAL INDUCTORS WITH THE DIFFERENT N AT INNER DIAMETER OF 100 μm. THE METAL WIDTH AND SPACING OF INDUCTORS ARE 10 AND 2 μm, RESPECTIVELY

N	L_s (nH)	R_s (Ω)	C_f (fF)	C_1 (fF)	C_2 (fF)	R_1 (KΩ)	R_2 (KΩ)
12	34.03	32.49	35.3	40.3	82.4	3.71	1.84
10	22.05	26.31	31.4	26.2	52.7	5.49	3.26
8	13.10	19.26	25.6	20.9	37.1	7.11	5.97
6	6.84	13.06	18.0	15.5	23.0	6.63	5.57
4	2.85	7.87	9.0	12.6	14.8	12.26	18.78

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(M. Park, 1998)