On-chip Inductors and Transformer

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RFIC’s Planar Spirals

- 3-D solenoid
- 12x12 um for 0.4 nH

< 10 nH
- Eddy currents
- Not over actives
- EMI

NEC Electronics
On-chip Inductors

- 5nH to 2700nH

- Low Rdc, 9 \( \mu \text{m} \) thick gold
  RF skin effect

- Magnetic cores >100 \( \mu \text{m} \) thick
  Optimize to frequencies

- Low cost production processes

- Flexible design, trim-able

- Minimize EMI directly over active IC circuits

- Small; multiple inductors onto existing chips
Linear Gold Inductor

Form tiny gold coils

Gold wires

< 250 µm
loop height
54 µm
wire pitch

Electroplated gold line

5.0 kV  x200  150 µm
Gold Over Passivation Metals

18 μm thick gold bumps

TAB for LCD Driver ICs

9 μm thick Power Gold

Wire bond pad & interconnect line for microcontrollers

Publication:
Gold on IC

Aluminum or copper layers underneath gold OPM

Power Gold interconnects
Wire Bonds onto Gold Pads

- Wire bonds over actives
- Stronger gold-bold bonds
- 3x more gold in 2 mils wires than electroplated gold on-chip

Gold pads
Toroidal Gold Inductor

700 µm diameter; measures 8 nH from 1-300 MHz

Q = 7
Advantages of Gold Inductors™

- Tiny: < 1 mm diameter x 0.25 mm height
  Fits 1 mm thin QFN packages

- Integrate 2, 4, 16 or more on-chip inductors
  Add onto existing ICs

- Gold ball bonds + electroplated thick gold
  Production ready, low cost
  Volume processes & tools

- Lower cost than discretes (0402 chip-inductors)

- Alter inductance by adjusting wire loop height

- Gold is ideal > GHz, RF frequencies
Inductor Physics

\[ L = \mu_0 n^2 l A \]

L = inductance value

\( \mu_0 = 4\pi \times 10^{-10} \) Henry/mm

n – number of turns/unit length

l – length of inductor coils

A – cross-sectional area of linear inductor
Larger Air Core Toroids

Toroidal inductors; 1.0 mil Au wires; 10 mil loop height

Inductance (Henry)

Circular Area (mm²)

Practical limit
Too large

128 turns_1.0 mil
64 turns_1.0 mil
32 turns_1.0 mil
16 turns_1.0 mil
Ferrite Core Gold Inductor

9 Turns
1x2x0.2 mm
150 nH
Q = 6
@ 2.4 MHz
11 Turns Gold Inductor

Ring oscillator, transistors test structures underneath inductor to evaluate interference.
Rdc & Inductances

Ferrite Cores measured @ 5 MHz

2 ferrite materials

Parallel wires

Measurements: Marilyn Stuckey & Hanyu Sheng

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Magnetic Field Lines

Ferrite core
35 turns coil designed to keep the EM field lines within the core, parallel to IC surface

>1500 nH

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www.PowerGoldConsultant.com
Isat > 1A

Measured L @ 5MHz decreased less than 1%; tested to 1 A

Ferrite core
Designing Transformer
primary/secondary coils

Insulator between two layers minimizes eddies

35 turns; permalloy core 2.7 μH
Material Possibilities

Inductor cores:

- Air (lowest cost)
- Ferrites (130 µm thick)
- High permeability permalloy (105 µm thick)
- Glob-top with magnetic filler particles
- Other materials not yet tried
- Round, rectangular, octagonal, etc.

Custom for frequency, L, Q
Ready for IC Evaluations

- Layout inductors over existing ICs
  Design & processes available
  Prototype then evaluate
  Characterize & optimize

- ESD, spike current protection

- Shrink hand-held devices

- Lowers cost

Publication:
“Flexible On-chip Inductors and Transformer”, J. Wang, IMAPS
Device Packaging Conf, Ft. McDowell, Arizona 10Mar10