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The Noble Art of De-coupling

1.

Introduction

Much of the electronics built today will require de-coupling of various points for various frequencies. What first comes to mind may be the V+ of IC's. If the IC is an aggressive one, providing fast transitions with a lot of drive capability, the problem is no longer a simple one.

Nevertheless it is treated as if it were! "Ah, let's toss in a 10000 'puff' there! Wait a moment, better make it a 1000 puff and a 'point-one'!" That is: a 1 nF and a 0.1µF capacitor.

For one thing, 1 nF or 0.1µF will make no difference (to RFI) above 500 MHz and almost none at 200 MHz! The capacitors are already well above their self-resonance frequencies.

The readers of VHF Communications do not have to be reminded about what will happen as clock frequencies are reaching the GHz mark! Even if the signals are not perfectly square, it is reasonable to assume that they are not sinusoidal either. Rise times may be of the order of 100 ~ 200 ps. It is thus proper to consider frequencies up to at least 2 GHz. (As things are going, do you too have the feeling that someone will laugh at this in a few years?!)

2.

Elements

My measurements have shown a 1206 capacitor to have ~ 1.8 nH and a 0805 seems to have ~ 1.5 nH. In some other applications it seemed like the 0805 had ~ 1 nH. Right or wrong, we can probably agree that it will have at least 1 nH and I will use it in the modelling. The Q of the inductance is probably not stellar, let me guess at 30. The Q of the capacitance may well be 50.

The source impedance of the transient generator is probably low. Let us use 10Ω for this and 100Ω for the other end, the "load", going to the power supply. We will treat the circuit like a filter, considering S11, S21, and S22 over frequencies to 3 GHz.

3.

Models

For the modelling I have used the Eagleware Superstar program, version 5.2

The first model we may want to take a look at is the one with a single de-coupling capacitor on the V+ pin of the IC (Fig 1). It is imagined here as

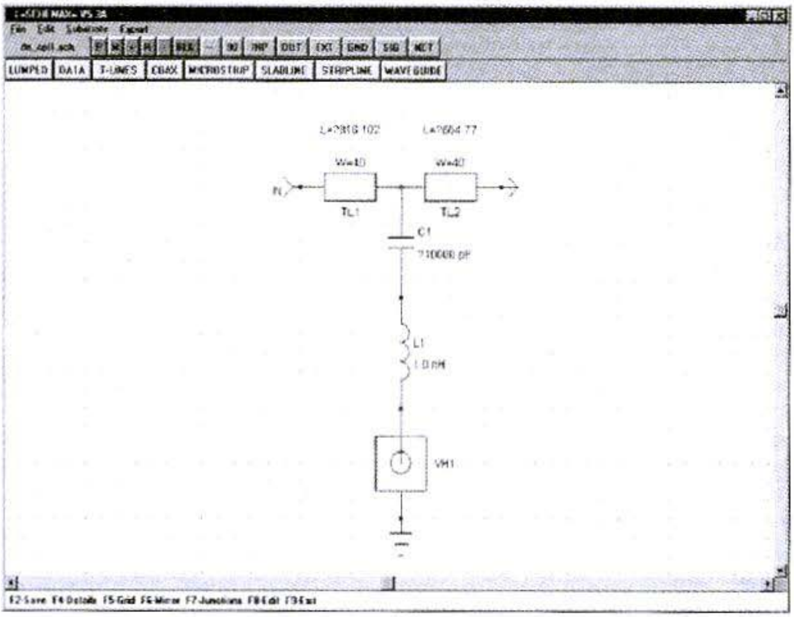

Fig 1: Circuit of the first model

"IN>"

The model, showing a piece of 40 mils (1 mm) wide track to the capacitor, another track to the 100Ω load. Their lengths are mostly inconsequential. The capacitor is pictured with its inductance and it is grounded through a via hole of 24 mils diameter with 1.5 mils metal. The substrate is 32 mils Rogers 4003, with εr=3.38 nominally, but various substrates would not make any great difference here.

4.

Simulations

On the left diagram (Fig 2) are S11 and S22 with 0 ~ 1 dB vertically. On the right is S21 on a 0 ~ 100 dB scale, showing the efficiency of the de-coupling. Four marker frequencies are set under each graph and their "dB" results can be read along the bottom.

One set of graphs is dashed and one set is solid. They represent a capacitance of 100 pF and 10 nF respective. Sure, there is a nice attenuation from ~500 MHz to ~30 MHz, but the rest is nothing to write home about. About 20 dB attenuation appears to be the rule, and it is not much of a de-coupling on an intense source of RF.

It appears likely that several stages, compounded, of de-coupling may do better. Let us look at a two stage solution and let SuperStar try to optimise it for -60 dB from 100 ~ 1000 MHz and -40 dB from 50 ~ 2000! (Fig 3)

Well, now we are getting somewhere! The attenuation is below 30 dB up to 1420 MHz! Two dips are visible, corresponding to the self-resonance of the capacitors. The program decided that they better be 587 and 3418 pF respective, with 802 mils from the left and a

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S11 ----                   S22 ----                   S21 ----
100         225            600         1000           100          225          600          1000
-2.02593    -0.585576      -.049509    -.054827       -4.53498     -10.5965     -29.7104     -22.1265
-1.9099     -0.430628      -.044453    -.095016       0            0            0            0
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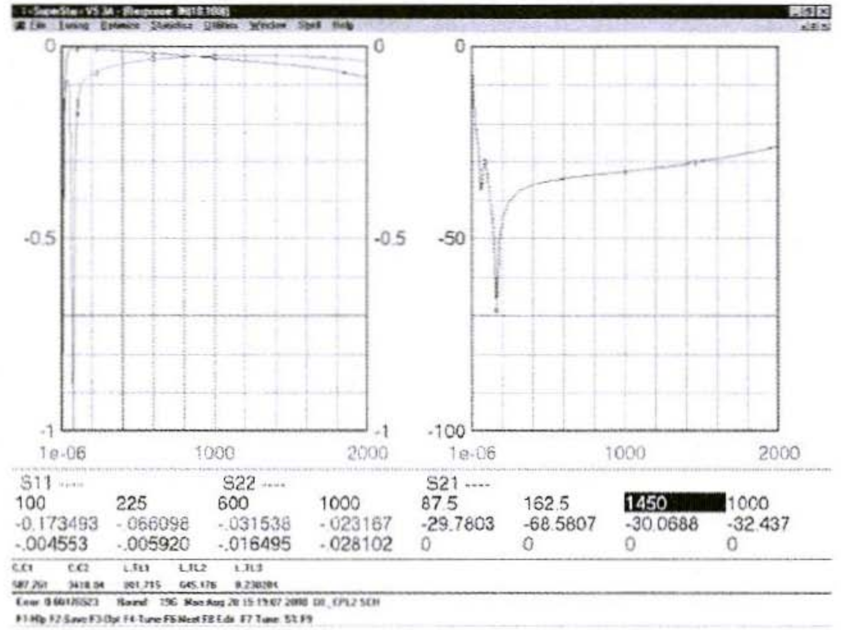
Fig 2: First simulation results



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S11 ----                   S22 ----                   S21 ----
100         225            600         1000           87.5         162.5        1450         1000
-0.173493   -.066098       -.031538    -.023167       -29.7803     -68.5807     -30.0688     -32.437
-.004553    -.005920       -.016495    -.028102       0            0            0            0
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Fig 3: Simulation of a two stage circuit

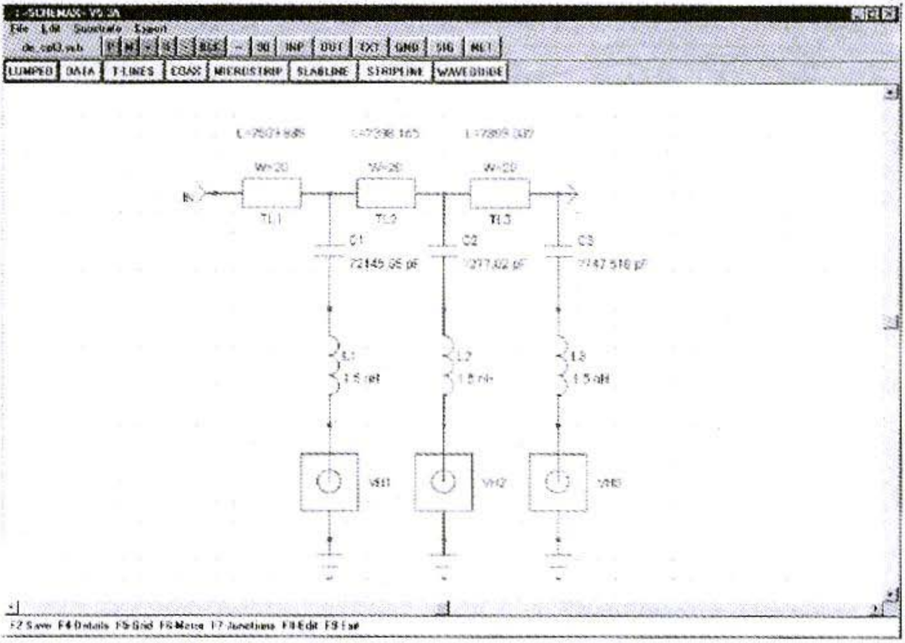


Fig 4: Circuit of expanded circuit

645 mils long lines in-between. The third line, at the right end, to V+, is best when short.

I expanded the circuit to three capacitors, with a 0.5 mm line before each, ran SuperStar on it again for the following configuration (Fig 4)

Indeed, this net shows a very good performance with 50dB from 150 ~ 400 MHz and 40 dB from 80 ~ 2212 MHz. Notice that the max frequency is changed from 2 to 3 GHz! (Fig 5)

On the S11 numbers can we see how pin 8 on the IC finds a near total reflex (<0.1 dB Return Loss) on almost all frequencies although the phase rotates via inductive to near open. (Fig 6)

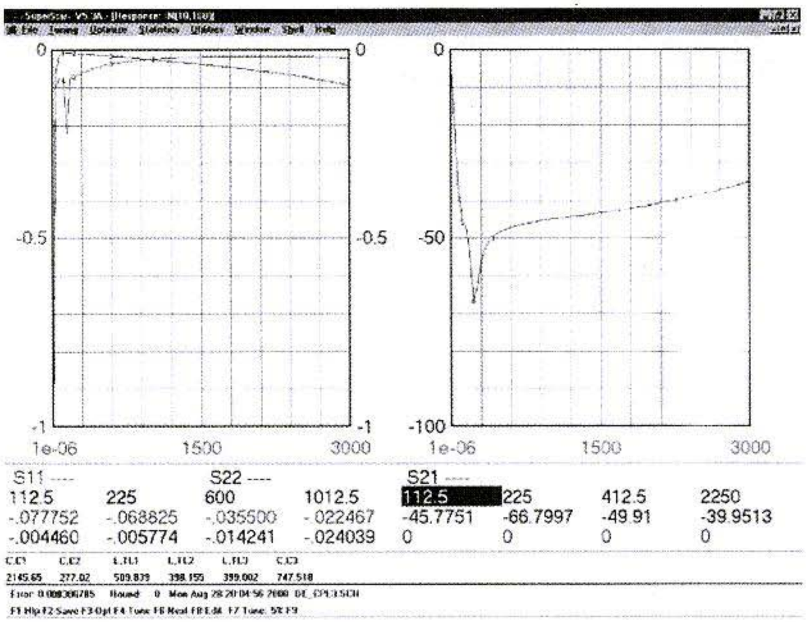
One possible practical realisation of this net with a Small Outline 8-pin IC and 0805 components.

5.

Conclusions

Use of self-resonant capacitors for de-coupling has been known for most of the radio era. I have a book (that I cannot find just now) from the 1930's. In it is a graph of the "ideal length of de-coupling capacitors vs. frequency". From the values, clearly some 5 ~ 10 nH per cm was anticipated. I am not so sure it was considered in old IF strips and other circuits, but some designers surely knew about it.

As frequencies move up in the VHF and UHF range, so do the number of capacitor values one do no longer have to consider using! The 1 nF capacitor in a 1206 surface mount package will become self resonant at 130 MHz. In a leaded package it will resonate at a much lower frequency. 1 nF can possi-



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S11 ----                  S22 ----                  S21 ----
112.5      225       600       1012.5     112.5      225       412.5    2250
-.077752   -.068825  -.035500  -.022467   -45.7751   -66.7997  -49.91   -39.9513
-.004460   -.005774  -.014241  -.024039   0          0         0        0
C.C1     C.C2    L.TL1    L.TL2    L.TL3    C.C3
2145.65  277.02  509.839  398.155  399.002  747.518
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Fig 5: Simulation of expanded circuit

bly be used at 146 MHz if it is a disk that is soldered direct between ground and the point to be de-coupled.

As the frequencies go up the problem becomes more difficult. At 1296 MHz the 10 pF capacitor nears resonance!

This article may not have much of a solution, if there is one, but should at least have brought attention to the phenomena, and got the reader thinking.

It is possible that the problem can be divided up. Since fairly good results was reached down to ~100 MHz, shielded compartments and separate de-coupling of the "lower" frequencies may well be possible. Since it will take up a lot of real estate, it has to be planned for early in the design.

A novel and interesting treatise of the inductor, and it's self-resonance(s) by Randy Rhea (Founder of Eagleware) is recommended reading.

His findings and conclusions are found. The articles can be down-loaded on PDF format from and select 1997, the Nov-Dec issue from the Archive! The title of the article is: "A Multimode High-Frequency Inductor Model"

For the second article, select the November 2000 issue! The title of this article is: "Filters and an Oscillator Using a New Solenoid Model".

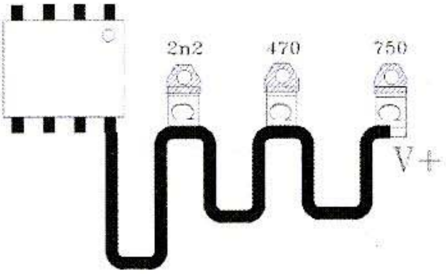

Fig 6: Practical realisation of the circuit