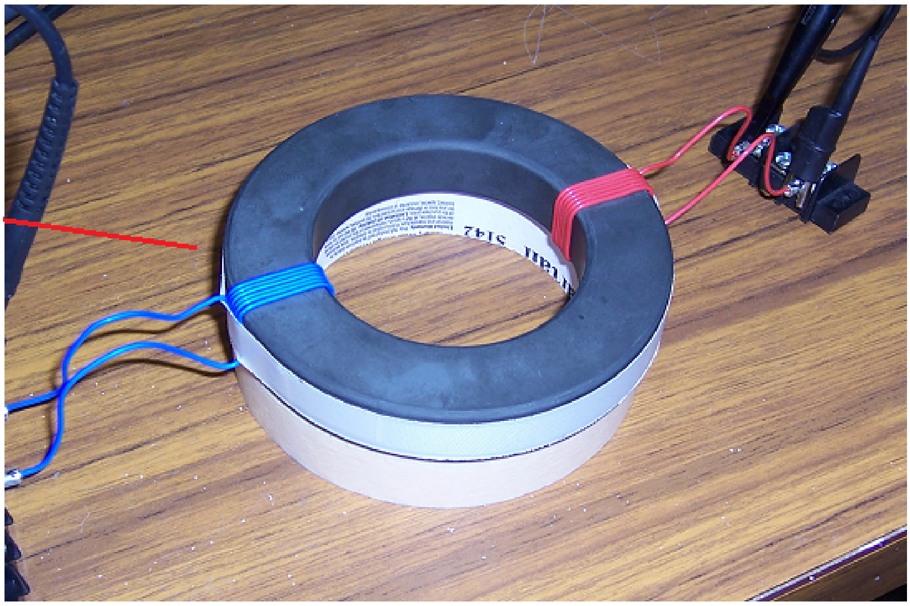
Comparison of MDT Measurements with Magnetic Domain Transmission-Line Analysis

The MDT measurements were those taken by Graham on a single 3F4 ferrite toroid having 6 turns primary and secondary, see picture below.

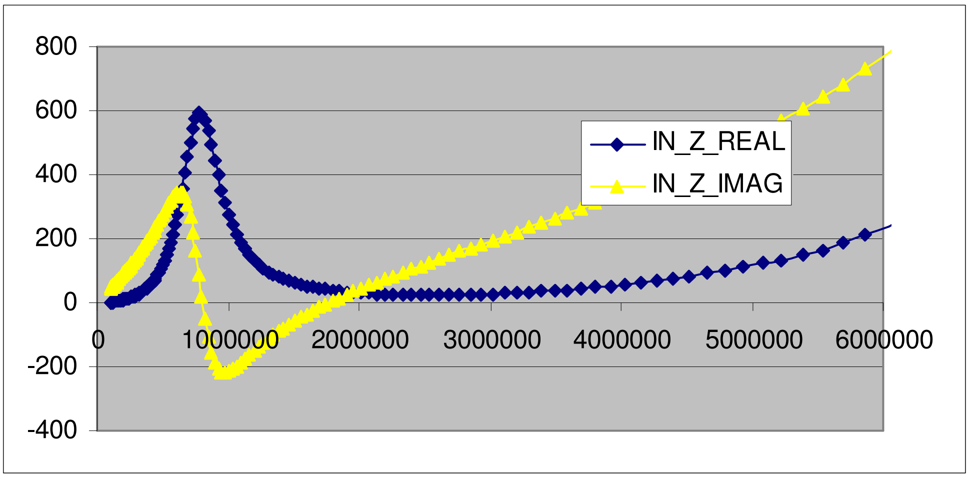


The secondary was loaded with resistor values ranging from 10M ('scope probe) down to 1K shunted by capacitor values ranging from 10pF ('scope probe) up to 500pF. Input voltage, current, and phase angle were measured over a frequency range from 100KHz to 20MHz. From these measurements the input impedance has been calculated for comparison with values obtained from an analysis where the transformer is modelled in the magnetic domain. Here the magnetic circuit is modelled as a form of transmission line where account can be taken of the propagation time from primary to secondary and vice versa. In this model the propagation velocity is taken as that which pertains at microwave frequency, i.e. c/sqrt(K*μ_R) where c is light velocity, μ_R is the relative permeability (900 for 3F4 ferrite) and K is dielectric constant. Since the dielectric constant is not published, this value is input as a control variable which conveniently allows a quick change to zero propagation delay when K=0. It is of interest that the theoretical model gives a best fit to the measurements when K=0.7.

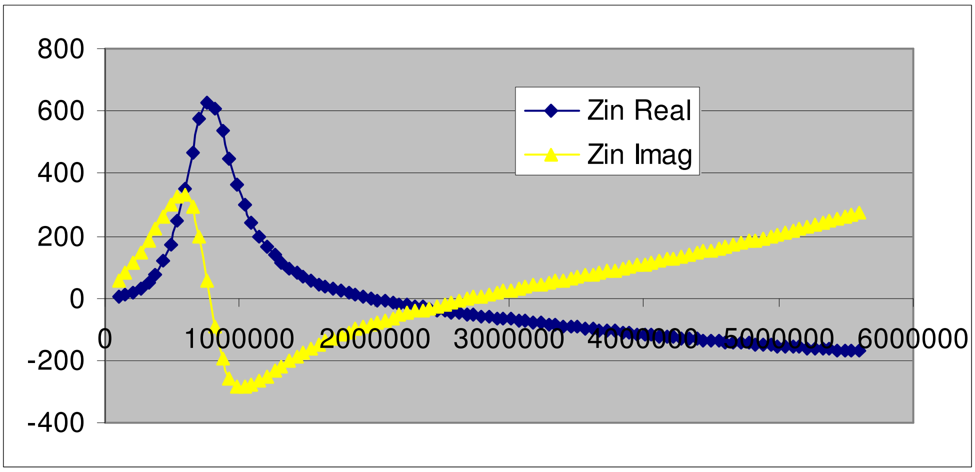
With capacitive loading and non-zero propagation delay the model predicts an input resistance that goes negative at a frequency somewhat above the LC resonance, which is of interest because that offers the possibility of self oscillation. Although negative resistance is not found to occur in the measurements (except at high frequencies where this is considered to be a measurement artifact), this short paper compares the theoretical and measured input impedances to show in which area further investigations should occur. Indications are that the set-up is not far from achieving that negative resistance goal.

The magnetic transmission line consists of distributed series $\mathcal{R}$ (actually reluctance) and shunt $\mathcal{G}$ (actually permeance). Such an electric line would have a characteristic impedance of $\mathcal{Z}_0$=sqrt($\mathcal{R}/\mathcal{G}$), and this is taken as the magnetic impedance of the line. The shunt permeance models the leakage flux which must occur when primary and secondary appear on opposite sides of the core. The current model really covers a long thin rectangular core where the impedance is constant along the transmission path. The circular core can be modelled by multiple sections having different line spacings but this has not been done yet (the existing model uses 45 spreadsheet columns, extending that to say 10 sections would take the column count to 450!!). Load resistance and capacitance reflect into the magnetic circuit in the manner described in my paper “Analysing Transformers in the Magnetic Domain”. Thus the capacitor C appears as a negative reluctance of value ω^2N^2C and the resistor R as a “magnetic” inductance of value N^2/R. Losses in the core are accounted for using the published complex permeability for the 3F4 ferrite, where μ” is used to calculate a distributed series “magnetic” inductance. Thus the line then appears as series $\mathcal{R}$ and $\mathcal{L}$ so the characteristic impedance becomes $\mathcal{Z}_0$=sqrt(($\mathcal{R}$+j$\omega\mathcal{L}$)/$\mathcal{G}$) (where all the values are of course magnetic ones).

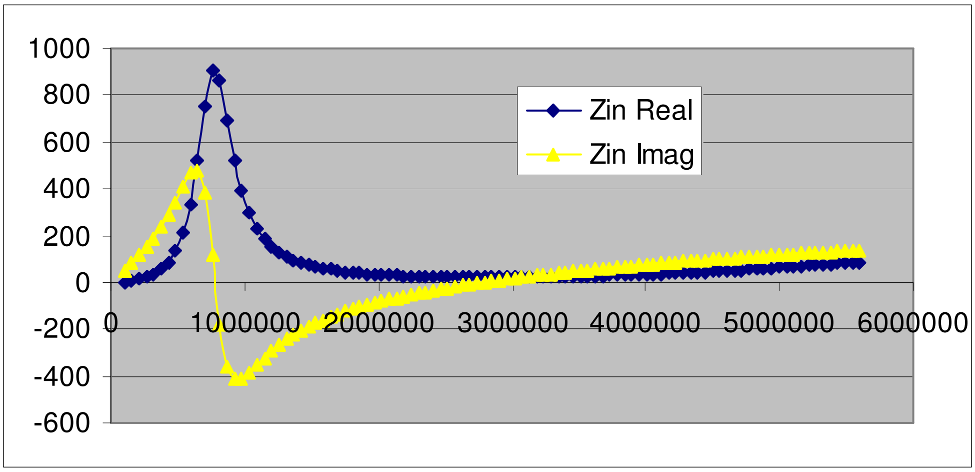
In most of the following charts the frequency scale is truncated at 6MHz so the abnormal measurement artefact around 12MHz is not seen. For the lowest value capacitor value of 10pF the model predicts a negative excursion of Rin close to that 12Mhz anomaly so there the frequency scale extends to 14MHz.



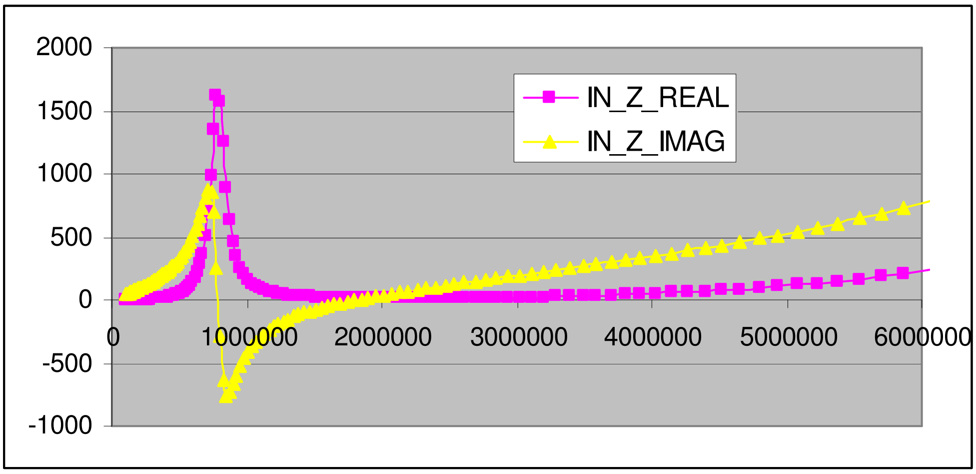
500pF 1K measured



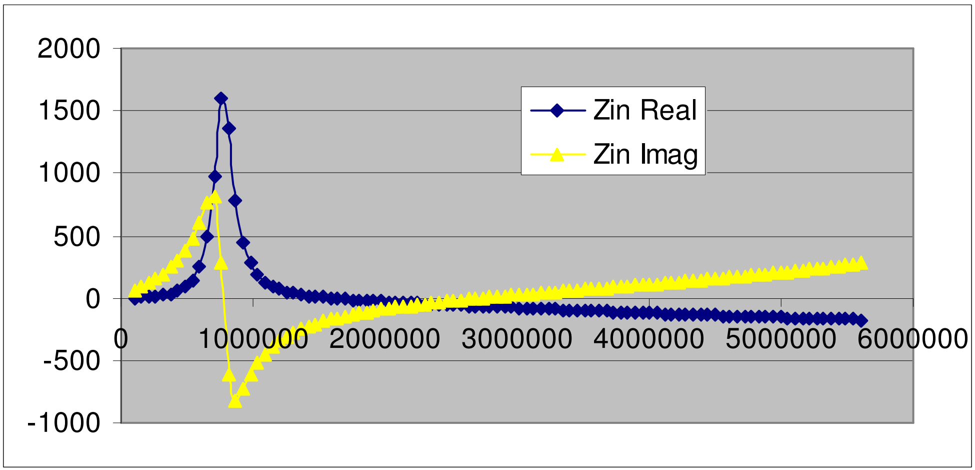
500pF 1K Theoretical with K=0.7



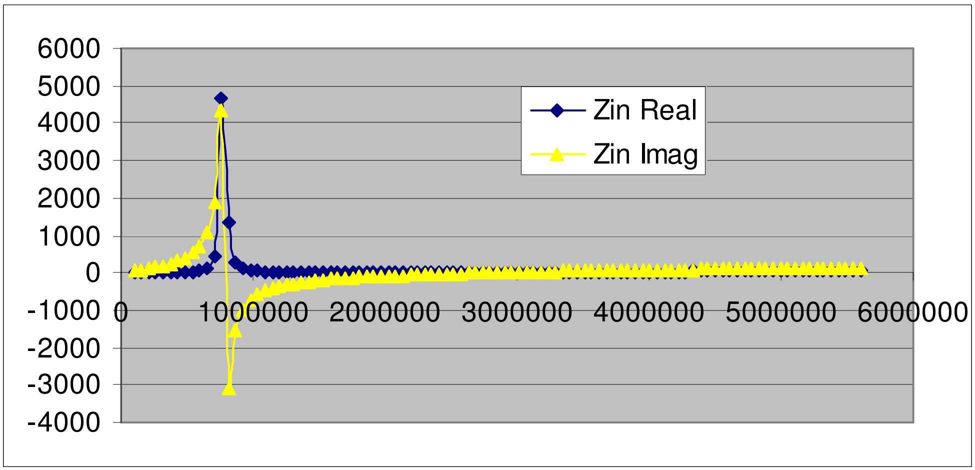
500pF 1K with zero delay (K=0,) (note vertical scale change)



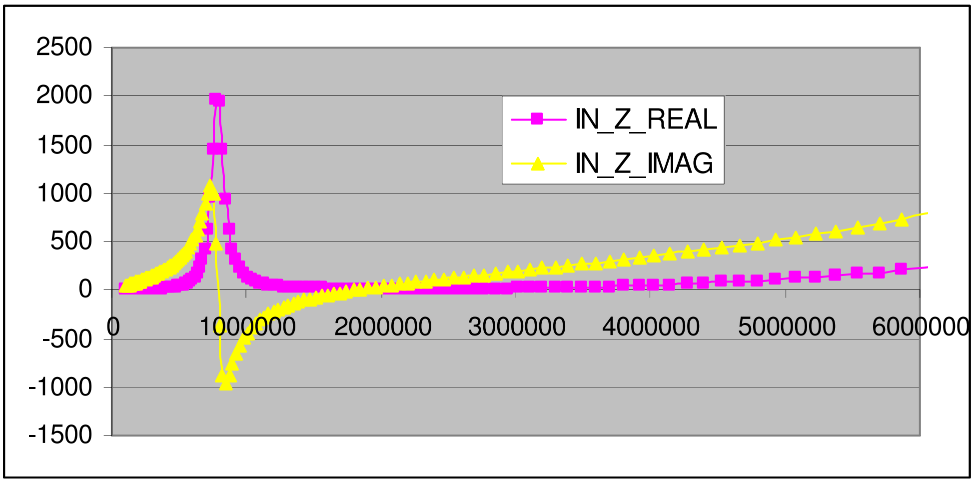
500pF 10K Measured



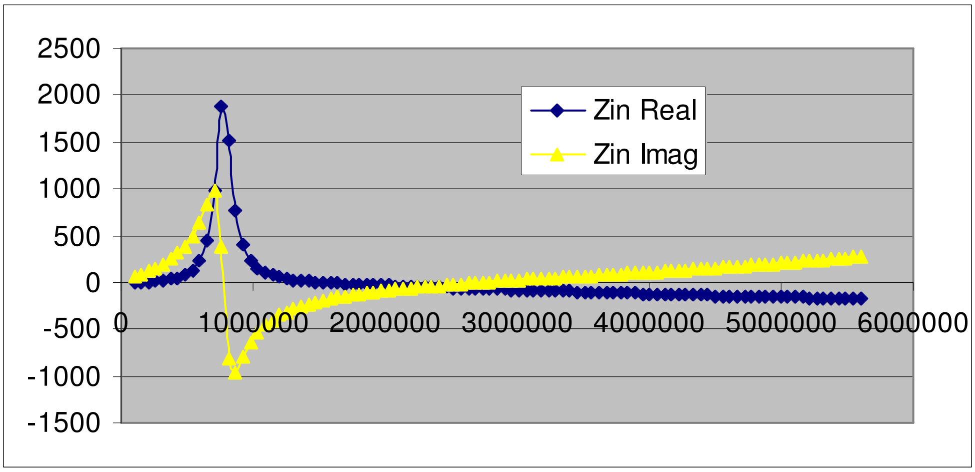
500pF 10K Theoretical with K=0.7



500pF 10K with zero delay (K=0), (note vertical scale change)



500pF 100K Measured



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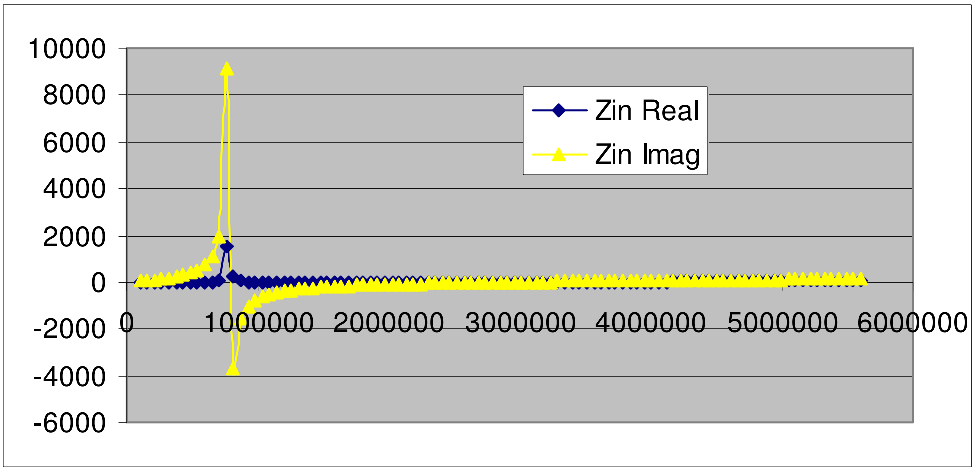

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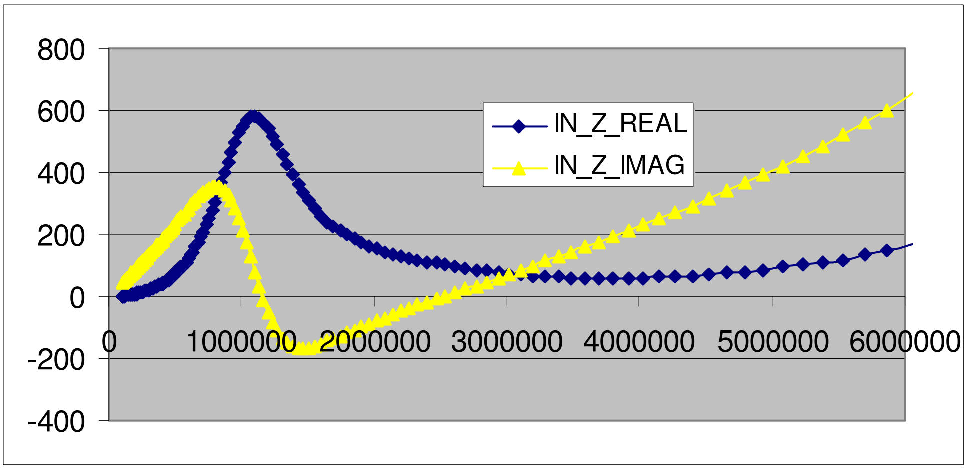
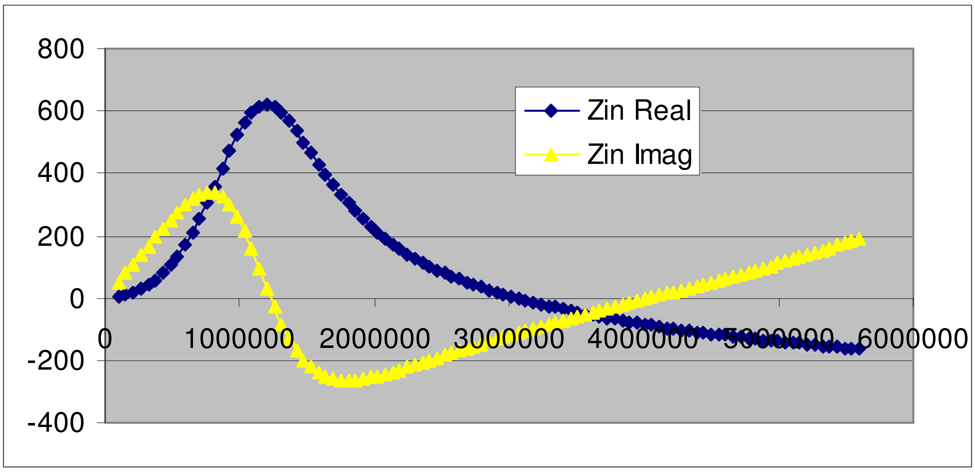
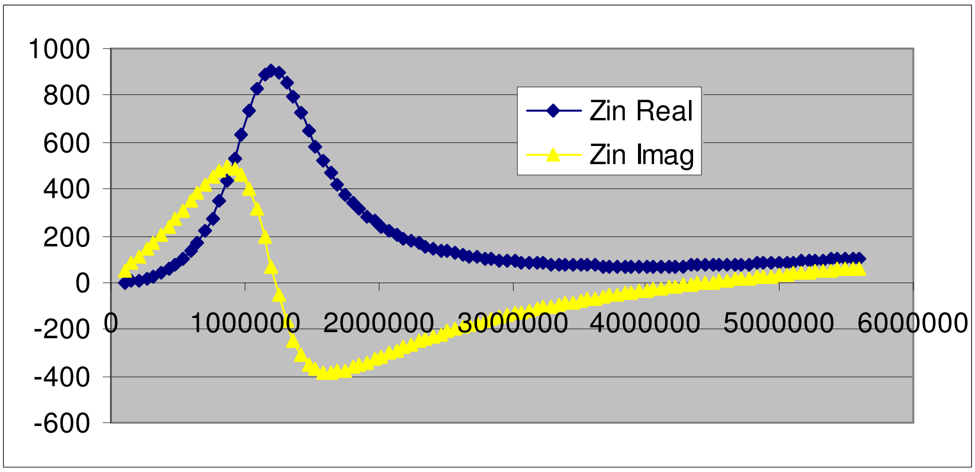


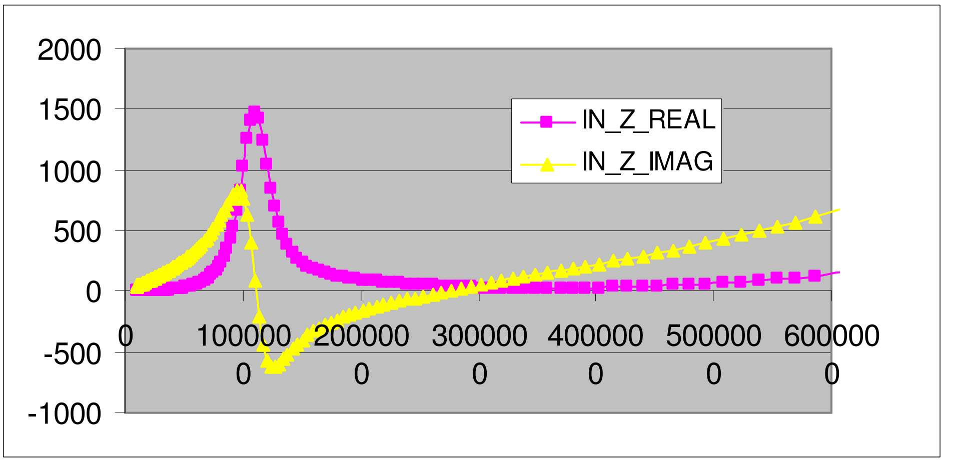
200pF 1K Measured



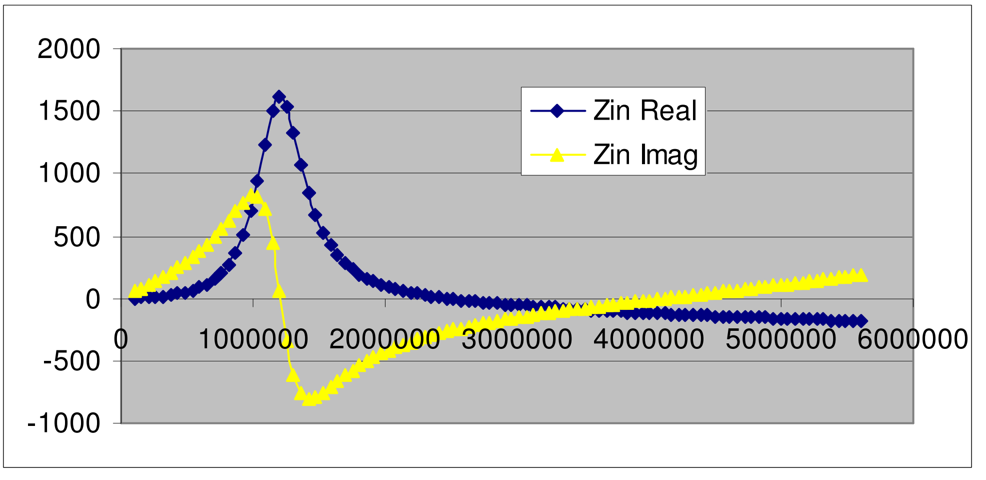
200pF 1K Theoretical with K=0.7



200pF 1K with zero delay (K=0), (note vertical scale change)



200pF 10K Measured



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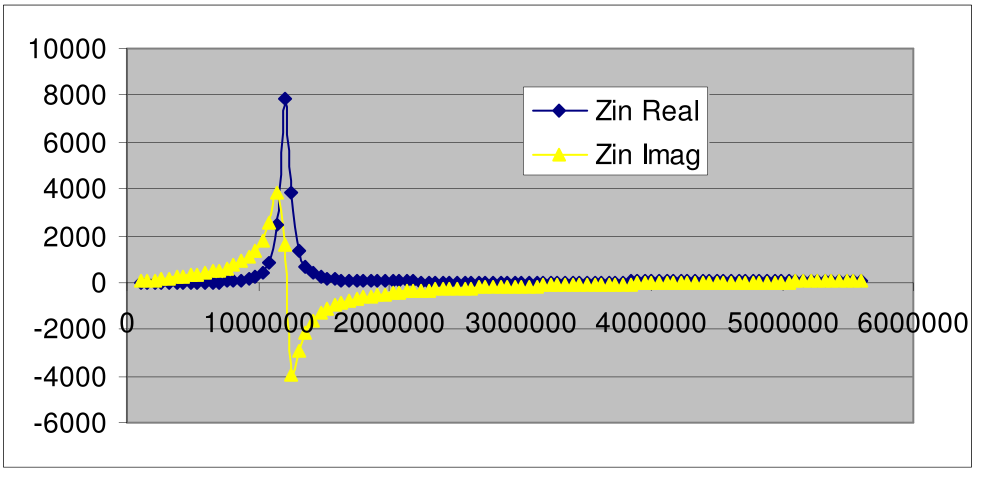

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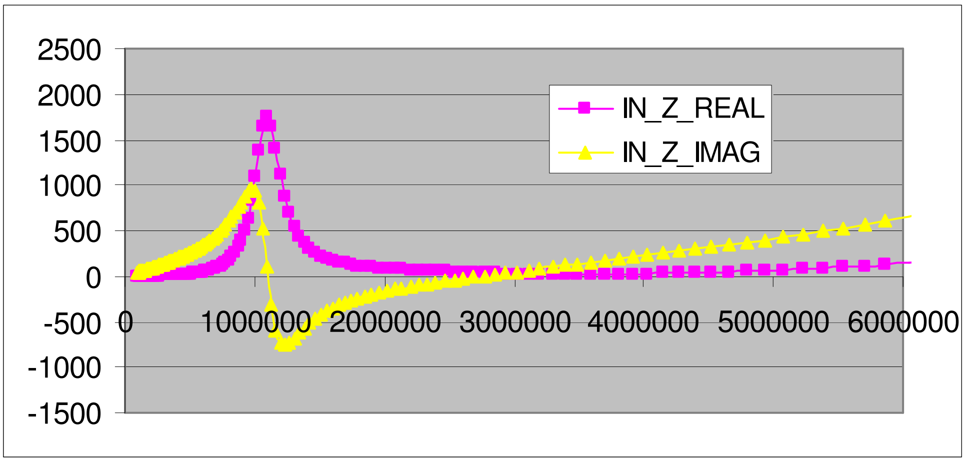
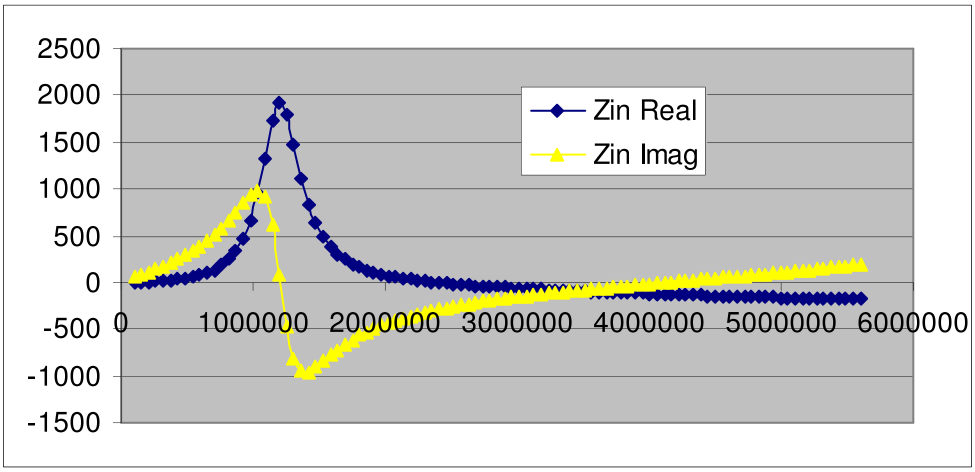


200pF 100K Measured



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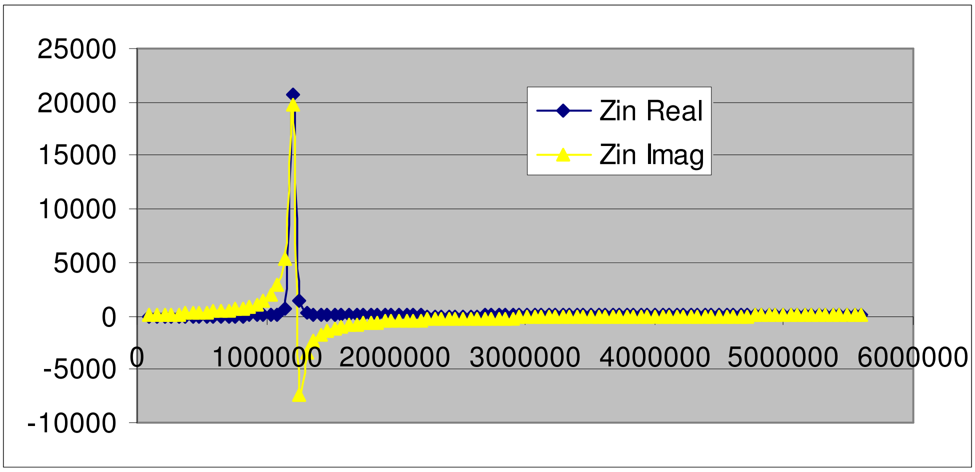

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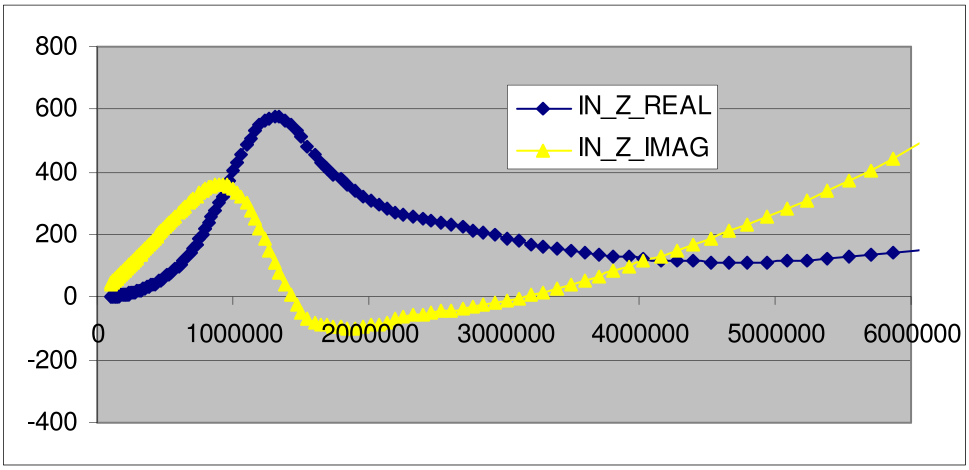
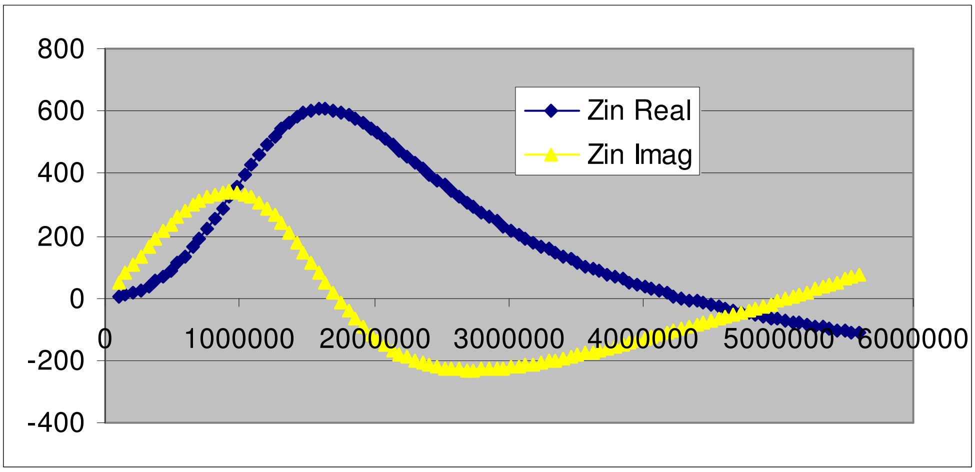


100pF 1K Measured



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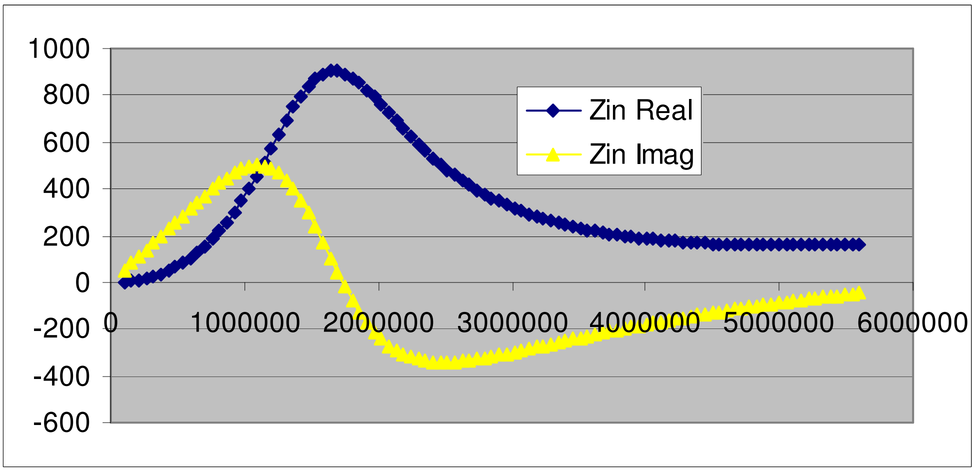

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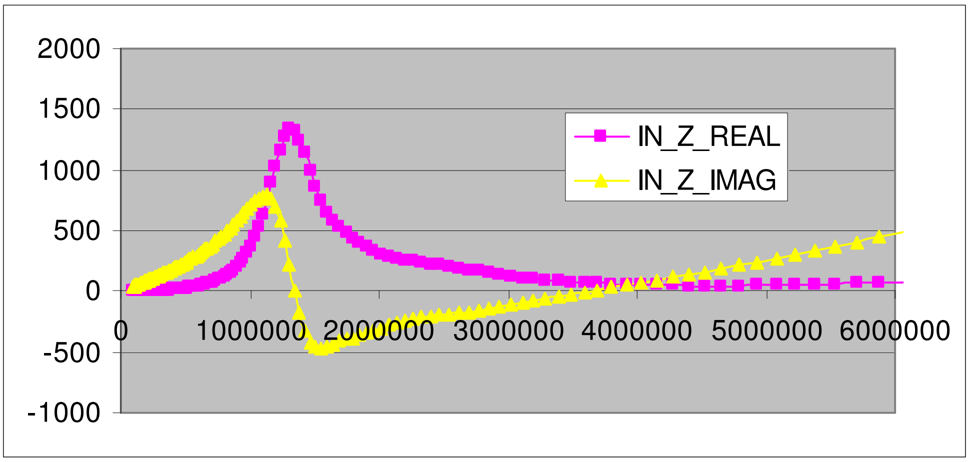
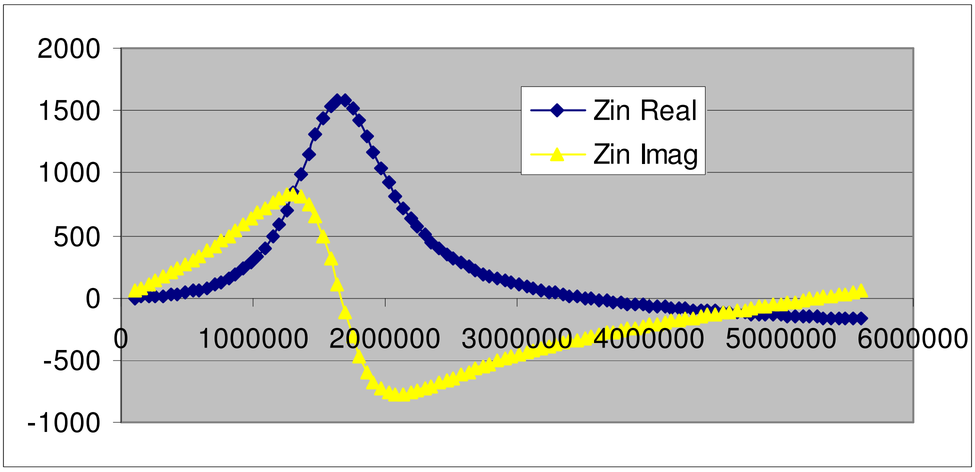


100pF 10K Measured



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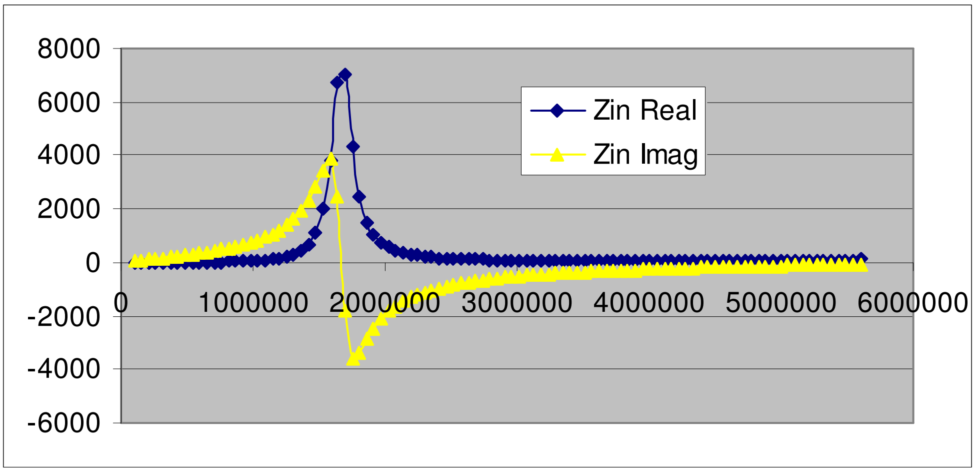

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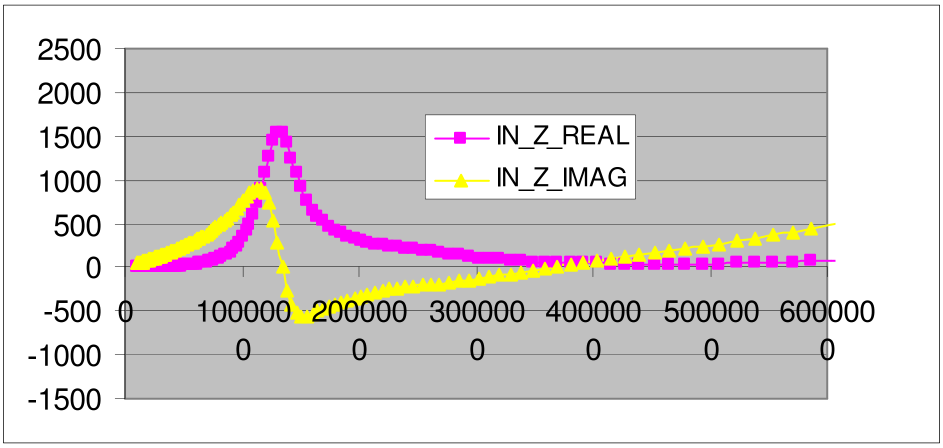

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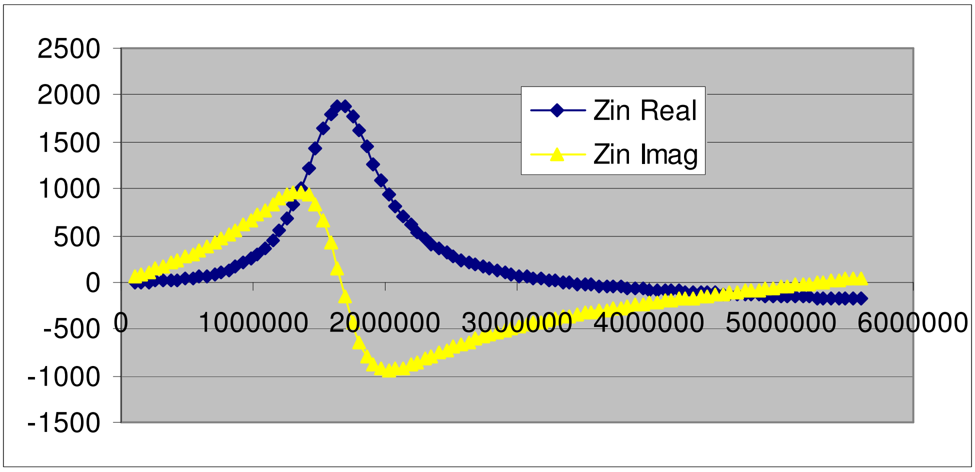

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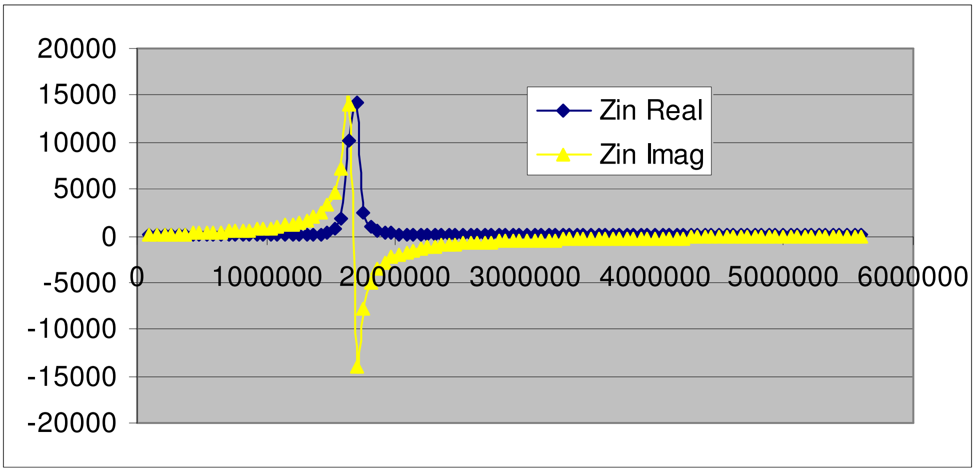

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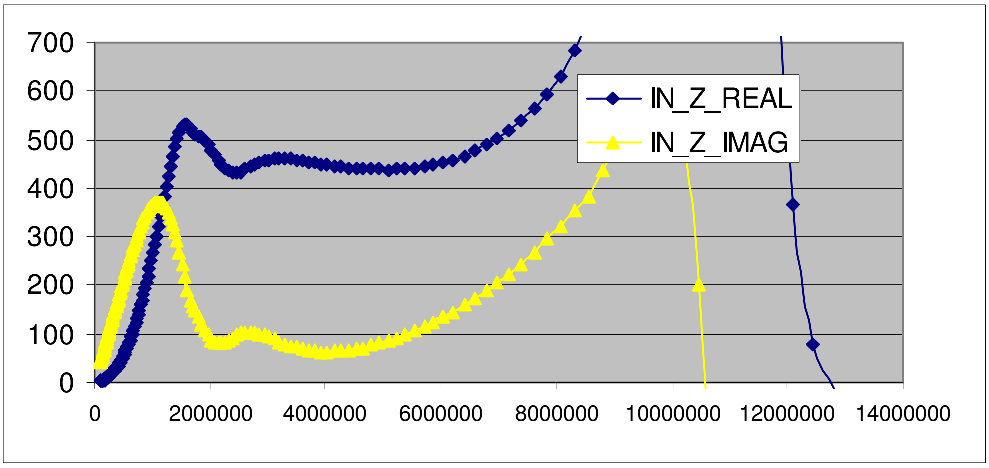
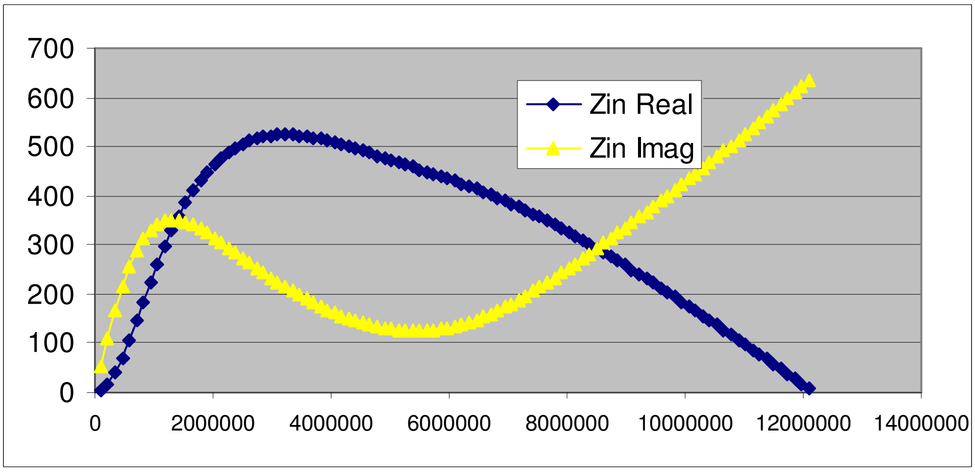


10pF 1K Measured



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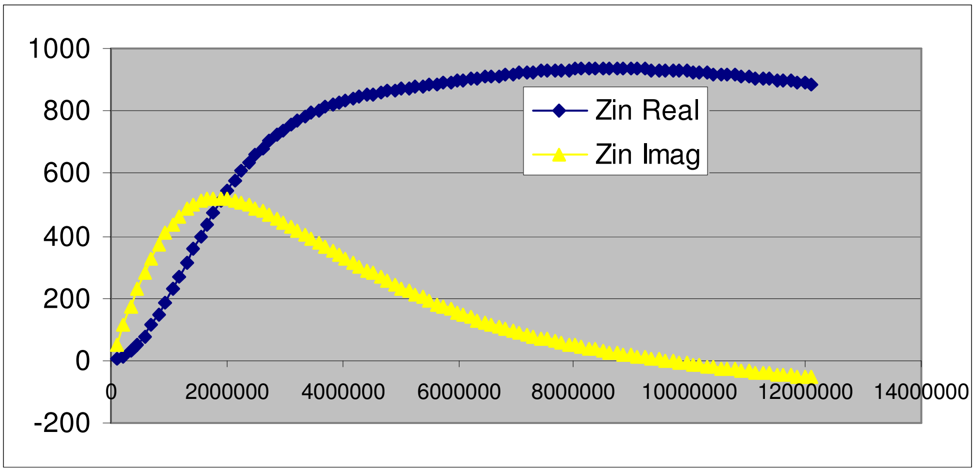

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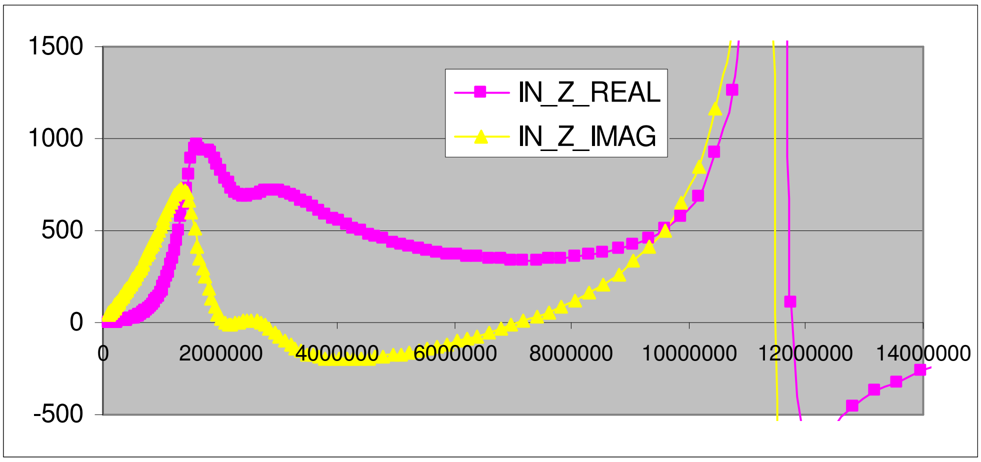

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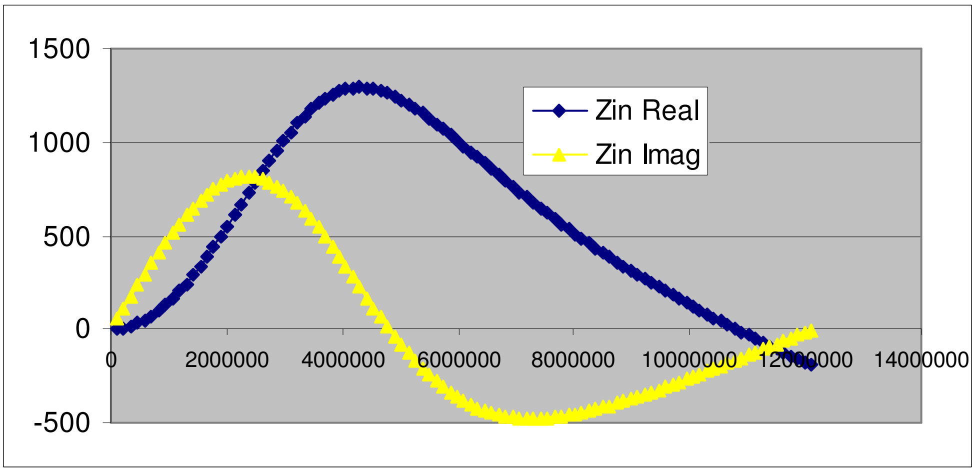

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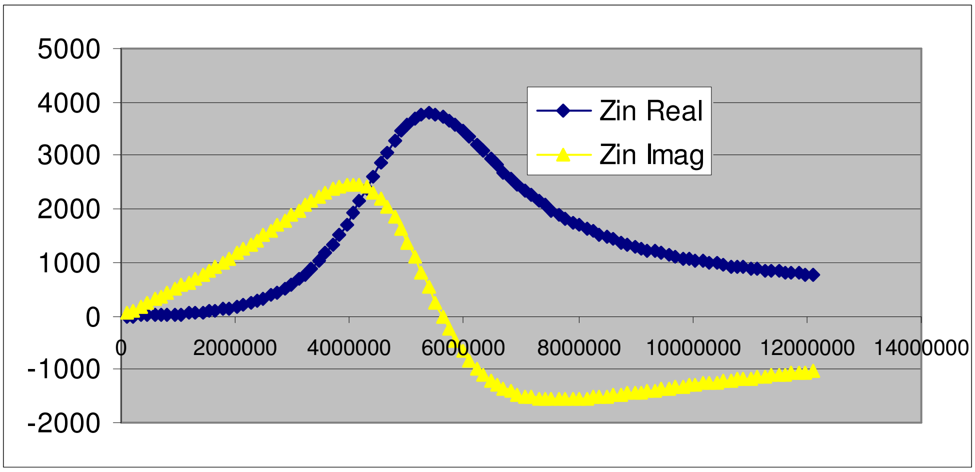

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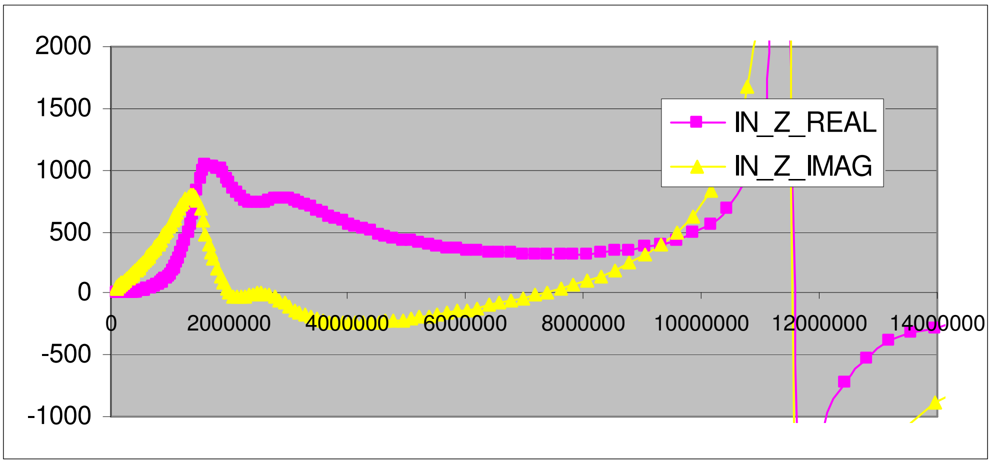

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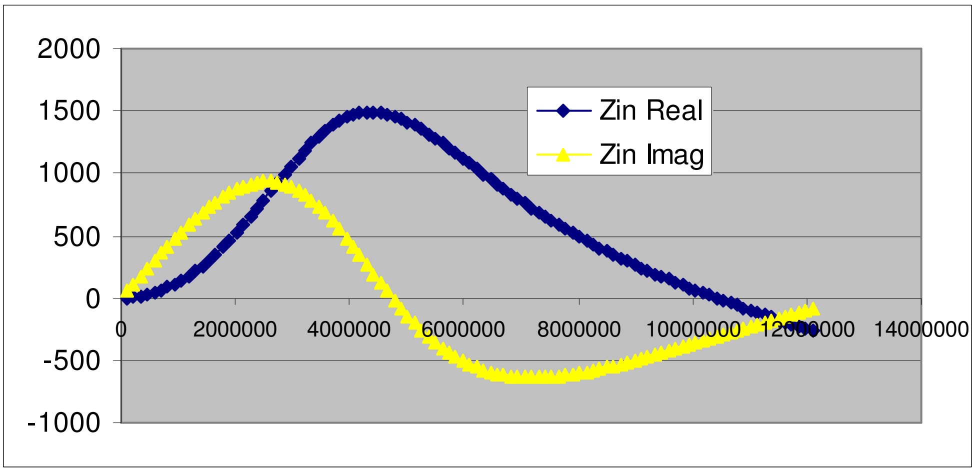

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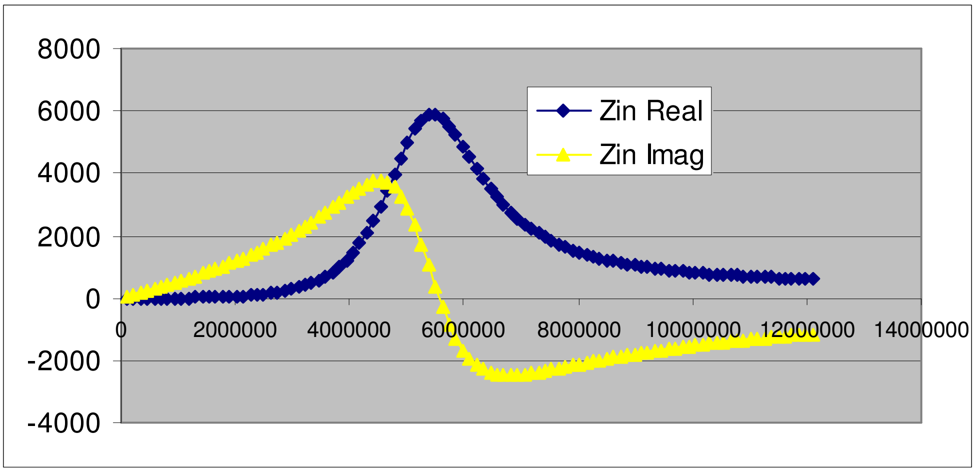
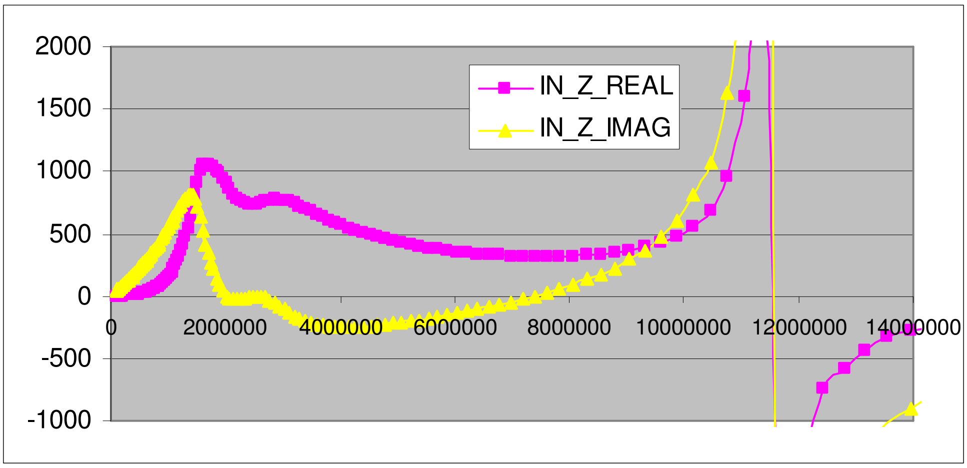
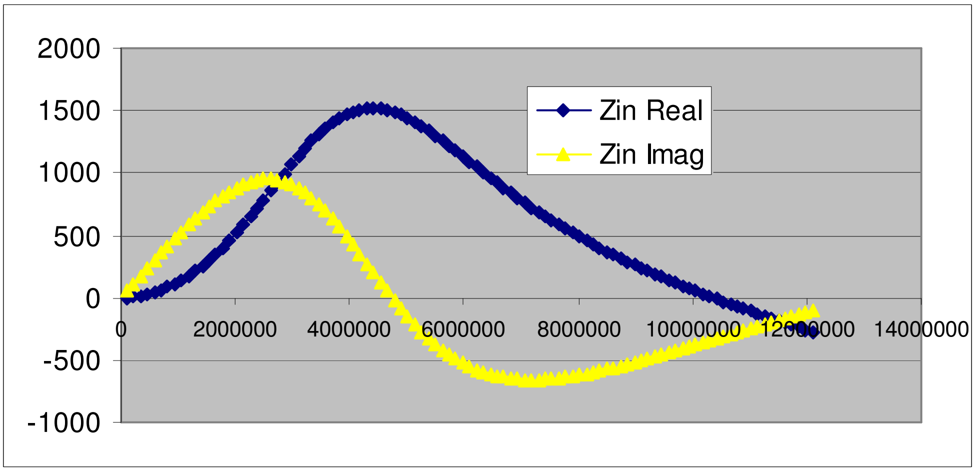


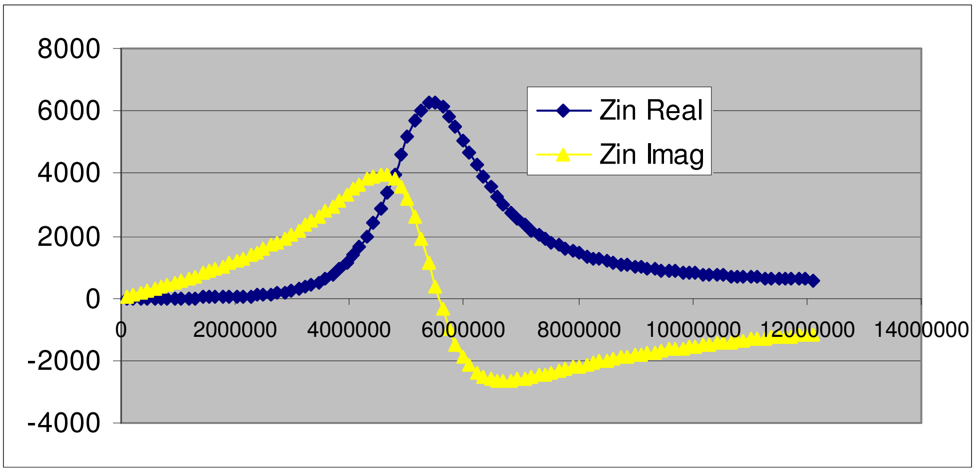
10pF 100K with zero delay (K=0), (note vertical scale change)



10pF 1M Measured



10pF 1M Theoretical with K=0.7



10pF 1M with zero delay (K=0), (note vertical scale change)