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Low-Frequency Effects of AC Coupling Capacitor

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Summary

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- AC cap has low-frequency effects of baseline wonder that cannot be represented well by channel S-parameter.

- If channel includes AC cap, AC cap should be shorted (either physically or virtually) in channel S-parameter model, and an equivalent lumped cap should be placed outside of channel in time-domain simulation.

Low-frequency effect of AC cap

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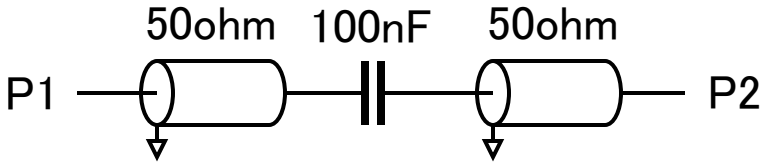
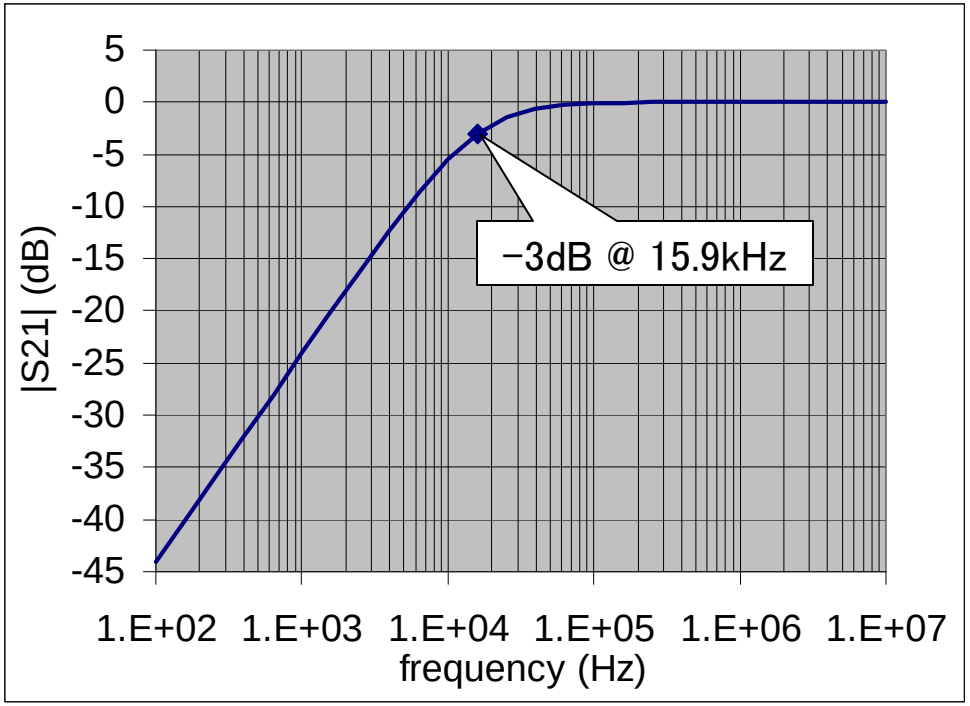
- High-pass characteristics with cut-off freq at kHz order
  - E.g. 100nF cap in 50ohm transmission line : -3dB cut-off freq = 15.9kHz





A problem of AC cap in Channel

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- Channel characteristics are often represented by S-parameter up to 40GHz with 10MHz frequency step

- To include the low-frequency effect of AC cap, frequency step must be 100 Hz ~ 1KHz at low frequency
  - Because the attenuation curve in low frequency must be captured
  - Otherwise, it is not possible to reproduce the effect of baseline wonder
    - Besides, discontinuity at low-frequency in S-parameter model often results in causality problem in time-domain simulation

- Channel S-parameter file grows by a factor of 10,000~100,000, exceeding practical limits of many tools
  - Some tool may support variable frequency steps, but most tools do not

A workaround for Simulated Channel

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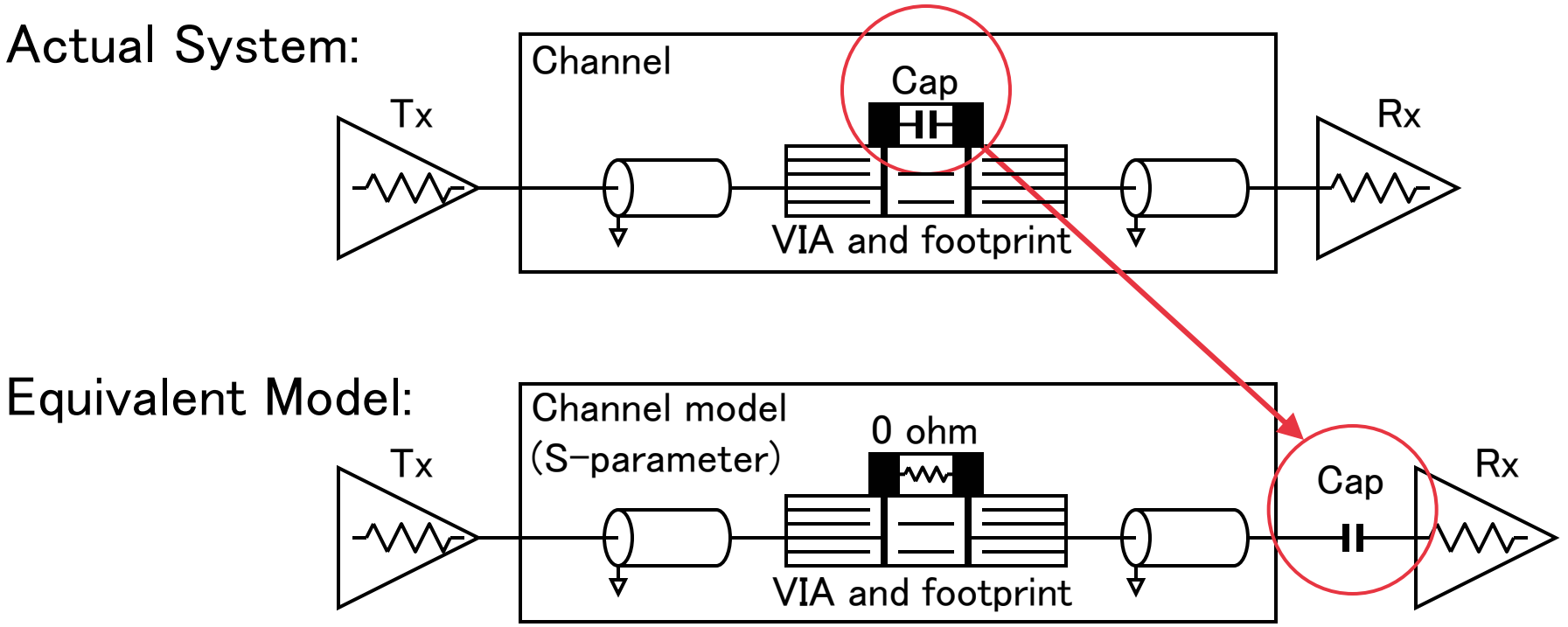
- Short AC cap to avoid discontinuity in low frequency in channel
  - Restrict impedance discontinuities in channel only at high frequency
    - E.g. VIA and SMT footprint
- Put an equivalent lumped capacitor outside of channel
  - Not in channel S parameter, but only in time-domain simulation



Actual System vs Equivalent Model

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- At High-frequency (> MHz order)
  - Almost no difference in either S21 or S11/S22 characteristics
    - Cap is almost zero (-0j) ohm at high frequency.
- At Low frequency (at kHz order)
  - Almost no difference on S21 characteristics
    - Lumped cap after channel reproduces almost same effect of baseline wonder.
  - Negligible difference in *phase* of S11/S22 characteristics
    - Distance and delay from Tx/Rx to capacitor are significantly changed.
    - However, phase difference is negligible, because distance is much shorter than wave length at this low frequency.
      - E.g. The wave length of 1kHz in material with Dk=4 is 150km.

Workarounds for Measured Channel (1/2)

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- Option 1 (same scheme as simulated channel)
  - Short AC cap *physically* by replacing it with 0 ohm resistor of the same form factor
  - Put an equivalent lumped cap outside of channel in time-domain simulation
  - Problems:
    - Replacing AC cap with 0 ohm may largely affect high-frequency channel characteristics
    - DC value is measured approximately at the lowest frequency supported by VNA that is such as 70kHz or 300kHz

Workarounds for Measured Channel (2/2)

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- Option 2 (measure with real AC cap)
  - Measure channel with AC cap only at high frequency (> MHz)
    - Do NOT measure at DC (or low-frequency at kHz order), because it is useless
  - Calculate DC value from measured high frequency values
    - Assuming that AC cap is *virtually* shorted
  - Put an equivalent lumped cap outside of channel in time-domain simulation
  - Problems:
    - DC value must be calculated, but there is no standard method
      - If calculation is not appropriate, it may result in issues such as causality
    - It is not clear who calculates DC values for channel models contributed to TF
      - Each user? It may cause inconsistent results between users
      - Contributor? It may be best if possible, but it causes extra burden on contributor
      - Someone else? Who? (I may volunteer to share some values, if there is demand)

Recommendation

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- If channel includes AC cap
  - Short AC cap in channel S-parameter model
    - Simulated channel:
      - Short AC cap with ideal conductor
    - Measured channel:
      - Short AC cap physically by replacing AC cap with 0 ohm resistor, and measure DC value approximately at the lowest possible frequency

        or
      - Calculate DC value from high-frequency values measured with AC cap assuming AC cap is virtually shorted (no measurement at DC or low frequency)
  - Put an equivalent lumped cap outside of channel in time-domain simulation