4. Snubber design (RC snubber)

- RC snubber → Secondary side diode
4. Snubber design (RC snubber)

- Why Diode voltage oscillates when turned off?
  - Oscillation between the leakage inductance and diode output capacitance
  - Need to be damped with additional resonant network

\[
R = \frac{L_{ik}}{\sqrt{C_{out}}} = \sqrt{\frac{L_{ik}C_{out}}{C_{out}}} = \frac{1}{2\pi f_r C_{out}}
\]
4. Snubber design (RC snubber)

(1) Measure the original resonance period ($T_r$) of the diode voltage waveforms.

(2) Find a capacitor value that doubles the resonance period when connected in parallel with the diode.

$T_r = 46\text{ns}$

$\rightarrow \text{With 680pF capacitor, the resonance period is approximately doubled (46ns} \rightarrow 96\text{ns})$
(3) Calculate the snubber resistor with the following equation.

\[ R_{sn} = \frac{3T_r}{2\pi C_{sn}} = \frac{3 \cdot 46\, \text{ns}}{2\pi \cdot 0.68\, \text{nF}} = 32\, \Omega \]  
(Use 30 ohms resistor)
4. Snubber design (RCD snubber)

- RCD snubber → Primary side

\[
P_{sn} = \left( \frac{V_{sn}}{R_{sn}} \right)^2 = \frac{1}{2} f_s L_{\text{IK}} (I_{ds \text{ peak}})^2 \left( \frac{V_{sn}}{V_{sn} - V_{RO}} \right)
\]
4. Snubber design (RCD snubber)

- **Experimental results (C_{sn}=2.2nF, R_{sn}=56k\Omega, f_s=66kHz)**

\[ V_{dc} = 140V, \ V_{ro} = 65V, \ V_{sn} = 122V, \ I_{pk} = 1.1A, \ L_{lk} = 3\mu H \]

\[ \frac{V_{sn}^2}{R_{sn}} = \frac{122^2}{56k} = 0.266W \]

\[ \frac{1}{2} L_{lk} I_{pk}^2 f_s \frac{V_{sn}}{V_{sn} - V_{ro}} = \frac{1}{2} (3u) \times 1.1^2 \times 66k \times \frac{122}{122 - 65} = 0.256W \]

\[ V_{sn}^2 = \frac{143^2}{56k} = 0.365W \]

\[ \frac{1}{2} L_{lk} I_{pk}^2 f_s \frac{V_{sn}}{V_{sn} - V_{ro}} = \frac{1}{2} (3u) \times 1.41^2 \times 66k \times \frac{143}{143 - 65} = 0.360W \]
4. Snubber design (RCD snubber)

- **Design Procedure**
  - **Measure the leakage inductance**: measure the primary side inductance with all other windings shorted
    - LCR meter is not always correct (Normally 50% error) especially the leakage inductance is small
  - **Determine the snubber capacitor voltage** ($V_{sn}$) considering voltage margin of $BV_{dss}$
  - **Calculate the snubber resistor using**
    \[
    R_{sn} = \frac{2V_{sn}(V_{sn} - V_{RO})}{L_{lk}f_s I_{pk}^2}
    \]
  - **Determine the snubber capacitor considering the snubber capacitor voltage ripple** (1~10nF)
  - **If the measured drain voltage is different from the designed value, leakage inductance should be calibrated using**
    \[
    L_{lk} = \frac{2V_{sn}(V_{sn} - V_{RO})}{R_{sn}f_s I_{pk}^2}
    \]
4. Snubber design (RCD snubber)

- Design Example ($V_{RO}=65V$, $V_{in}=265V_{ac}$ ($V_{DC}=370V$), $I_{pk}=1.5A$)

  - Measure the leakage inductance with LCR meter: 5uH @ 70kHz

  - Determine the snubber capacitor voltage considering voltage margin of BVdss: $V_{sn}=182V$ ($V_{sn}+V_{DC}=182+370=552V$ :85% of 650V)

  - Calculate the snubber resistor

  $$R_{sn} = \frac{2V_{sn} (V_{sn} - V_{RO})}{L_{lk} f_s I_{pk}^2} = \frac{2 \times 182 \times (182 - 65)}{5\mu \times 66k \times 1.5^2} = 57k\Omega$$
4. Snubber design (RCD snubber)

- Determine the snubber capacitor considering the snubber capacitor voltage ripple: \( C_{sn} = 2.2 \text{nF} \)
- Measured the peak drain voltage: 520V (\( V_{sn} = 146 \text{V} \))

\[
R_{sn} = 56k\Omega, \quad C_{sn} = 2.2\text{nF}
\]

\[
V_{sn} = 520 - 370 = 150\text{V}
\]

\# \( V_{sn} \) is different from the designed value

- Recalculate the leakage inductance with measured \( V_{sn} \)

\[
L_{lk} = \frac{2V_{sn}(V_{sn} - V_{RO})}{R_{sn}f_s I_{pk}^2} = \frac{2 \times 150 \times (150 - 65)}{56k \times 66k \times 1.5^2} = 3\mu\text{H}
\]
4. Snubber design (RCD snubber)

✓ Recalculate snubber resistor

\[
R_{sn} = \frac{2V_{sn}(V_{sn} - V_{RO})}{L_{lk}f_{s}I_{pk}^2} = \frac{2 \times 182 \times (182 - 65)}{3 \mu s \times 66 \times 1.5^2} = 95k\Omega
\]

\[R_{sn}=96k\Omega, \hspace{1cm} C_{sn}=2.2nF\]

\[V_{sn}=543-370=173V\]

✓ The drain voltage is lower than the designed value by 9V due to the stray resistance (Measured:543V, Designed:552)