

Module 2

Network Theorems

Introduction to Network Analysis

Linear Networks

Theorems apply strictly to circuits where parameters (R , L , C) remain constant regardless of voltage or current changes.

Bilateral Networks

Circuit properties or responses are identical in both directions (e.g., transmission lines, resistors).

Dependent vs. Independent Sources

Independent: Voltage/current output is entirely self-contained.

Dependent: Output value is controlled by a voltage or current existing elsewhere in the circuit.



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1. Superposition Theorem

Core Principle:

In any linear bilateral network containing multiple independent sources, the total response (current or voltage) in any branch is the algebraic sum of responses produced by each independent source acting alone.

Deactivation Rules for Independent Sources:

Independent Voltage Sources: Replaced by a short circuit (0V, zero internal impedance).

Independent Current Sources: Replaced by an open circuit (0A, infinite internal impedance).

Dependent Sources Rule:

Dependent sources are NEVER deactivated. They must remain active throughout the entire analysis.



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2. Reciprocity Theorem

Core Principle:

In any linear, passive, bilateral single-source network, the ratio of excitation to response remains constant if the positions of excitation and response are interchanged.

Operational Scenarios:

Case 1: An ideal voltage source V in Branch A produces a current I in Branch B.

Case 2: Shifting that same voltage source V to Branch B produces the exact same current I in Branch A.

Key Constraints:

Valid only for networks containing a single independent source.

Does not hold true for networks containing dependent sources.



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3. Thévenin's Theorem

Core Principle:

Any linear two-terminal circuit consisting of resistances and sources can be structurally replaced by an equivalent circuit containing a single ideal voltage source (V_{th}) in series with a single impedance/resistor (R_{th}).

Key Parameters:

Thévenin Voltage (V_{th}): The open-circuit voltage measured across the two designated load terminals.

Thévenin Resistance (R_{th}): The equivalent input resistance looking back into the network terminals with all independent sources turned off.



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4. Norton's Theorem

Core Principle:

Any linear two-terminal network can be fundamentally replaced by an equivalent circuit containing an ideal current source (I_n) in parallel with a single impedance/resistor (R_n).

Key Parameters:

Norton Current (I_n): The short-circuit current that flows when the two designated load terminals are directly shorted together.

Norton Resistance (R_n): Calculated identically to Thévenin resistance ($R_n = R_{th}$).

Source Transformation Link:

$$V_{th} = I_n * R_{th} \quad | \quad R_{th} = R_n$$



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Handling R_{th} / R_n : With vs. Without Dependent Sources

Network Configuration Type	Methodology to Find Equivalent Resistance (R_{th} / R_n)
Without Dependent Sources (Independent Sources Only)	1. Deactivate all independent sources (short-circuit voltage sources, open-circuit current sources). 2. Compute equivalent resistance directly using series and parallel reduction techniques.
With Dependent Sources (Mixed Sources Available)	1. Dependent sources CANNOT be deactivated; they must stay active. 2. Deactivate independent sources, then apply an external test source (V_{test} or I_{test}) to the terminals. 3. Compute $R_{th} = V_{test} / I_{test}$ using node/mesh equations.
Universal Alternative Method	1. Compute the Open-Circuit Voltage (V_{oc}) across the target terminals. 2. Compute the Short-Circuit Current (I_{sc}) across the shorted target terminals. 3. Calculate equivalent resistance: $R_{th} = V_{oc} / I_{sc}$.



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5. Maximum Power Transfer Theorem (DC)

Core Principle:

Maximum power is delivered from a source network to a variable load resistor (R_L) when the load resistance equals the internal Thévenin equivalent resistance of the network ($R_L = R_{th}$).

Key Formulas:

Maximum Power Formula: $P_{max} = (V_{th}^2) / (4 * R_{th})$

Circuit Efficiency:

At maximum power transfer, circuit efficiency is exactly 50% because an equal amount of power is lost internally within R_{th} as is delivered to R_L .



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AC Circuit Analysis Extension

Complex Impedance Handling:

Replace basic DC resistances (R) with complex impedances ($Z = R + jX$) to adequately track magnitude and phase transitions.

AC Maximum Power Transfer Condition:

If the load impedance ($Z_L = R_L + jX_L$) is fully variable, maximum power delivery occurs when Z_L is the complex conjugate of the source Thévenin impedance (Z_{th}):

$$Z_L = Z_{th}^* \implies R_L = R_{th} \text{ and } X_L = -X_{th}$$

Physical Significance:

The load reactance cancels out the internal system reactance, turning the overall architecture into a purely resistive resonant loop.