

GROUP_14_Experiment: 6

Design of a Ring Oscillator Using IC7404 and CD4007 Transistors

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Abstract—This paper presents the design methodology of a ring oscillator circuit using a IC7404 and CD4007 transistor and to observe its oscillatory behaviour.

Index Terms—Ring Oscillator, Propagation Delay, Oscillation Frequency, 74LS04, CD4007, Inverter Chain, Oscilloscope

I. APPARATUS REQUIRED

• 74LS04 Hex Inverting Gates:

- Description: The 74LS04 is a digital logic device containing six independent NOT gates (inverters), each performing a logic inversion operation. It is commonly used in TTL logic circuits.
- Specifications: See Table I for detailed electrical characteristics [5].

Parameter	Value
Logic type	TTL
Number of gates	6 inverters
Supply voltage (V_{CC})	4.75V to 5.25V
HIGH level input voltage (V_{IH})	Min 2V
LOW level input voltage (V_{IL})	Max 0.8V
HIGH level output current (I_{OH})	−0.4 mA
LOW level output current (I_{OL})	8 mA
Propagation delay (t_{PLH}/t_{PHL})	3–15 ns
Operating temperature range	0°C to +70°C
Package types	DIP, SOIC, SOP
Power supply current (typical)	1.2–6.6 mA depending on output state

TABLE I: 74LS04 Hex Inverting Gate Specifications.

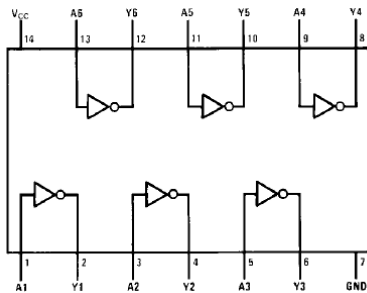


Fig. 1: 74LS04 Pin Configuration (14-Pin DIP/SOIC/SOP).

• CD4007 CMOS Inverter configuration:

- Description: A CMOS IC that includes three complementary pairs of N- and P-channel enhancement mode MOSFETs, suitable for logic-level switching and analog applications. All inputs are protected from static discharge by internal diode clamps.
- Specifications: See Table II for detailed electrical characteristics [6].

Parameter	Value
Supply voltage range (V_{DD})	3V to 15V
Operating temperature range	−40°C to +85°C
Storage temperature range	−65°C to +150°C
Maximum power dissipation (PDIP)	700 mW
Maximum power dissipation (SOIC)	500 mW
Quiescent current (I_L) @ 5V	0.005–15 μ A
Output drive (N-Channel) @ 10V	Up to 2.5 mA
Output drive (P-Channel) @ 10V	Up to −2.5 mA
Input capacitance	5 pF
Noise immunity (typ.)	0.45 V_{DD}
Propagation delay @ 10V	20–50 ns
Transition time @ 10V	30–50 ns
Applications	Analog switches, logic inverters, digital design

TABLE II: CD4007C Electrical Specifications.

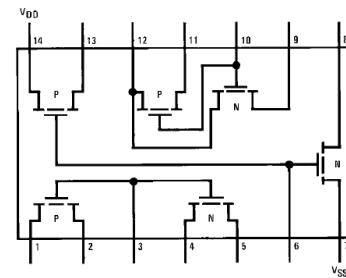


Fig. 2: CD4007C Pin Configuration (DIP/SOIC).

- **Power Supply:** Keithley 2231A-30-3 (triple output, 30V/3A).
- **DSO with Waveform Generator:** Keysight DSOX1102G (100 MHz, 1 GSa/s) for waveform analysis.
- **Breadboard and Connectors:** For circuit prototyping.

II. INTRODUCTION

A **ring oscillator** is a circuit composed of an odd number of inverter stages connected in a feedback loop. The circuit lacks a stable logic state and continuously toggles between high and low states, producing a periodic oscillating signal. This behavior results from the inherent propagation delay of each inverter.

In this experiment, we construct ring oscillators using two different ICs—**74LS04** (TTL inverter) and **CD4007** (CMOS inverter). The goal is to compare their oscillation frequencies and understand how delay and inverter type affect the performance. The frequency of oscillation is given by:

$$f = \frac{1}{2N\tau} \quad (1)$$

where N is the number of inverters and τ is the propagation delay per inverter.

III. THEORY

A ring oscillator operates due to the feedback of a signal through a chain of inverters. Each inverter introduces a delay, and with an odd number of stages, the signal continuously toggles, generating oscillations.

A. Necessity of Odd Inverter Stages

For the circuit to oscillate, the number of inverters in the loop must be odd. An even number of inverters would cancel out the inversion effect, resulting in a stable logic level. With an odd number, the feedback signal is always opposite in logic state, leading to continuous toggling due to delay.

B. Frequency Determination Principles

The total delay in the loop is $2N\tau$, accounting for rising and falling transitions. Thus, the frequency is:

$$f = \frac{1}{2N\tau} \quad (2)$$

where:

- f = frequency of oscillation
- N = number of inverters
- τ = propagation delay per inverter (depends on IC family)

C. Advanced Applications

Ring oscillators have several practical applications:

- On-chip clock generation for digital circuits
- Measurement of gate delays and process variations
- Temperature and voltage monitoring circuits
- Random number generation (with noise injection)

IV. DESIGN CALCULATIONS AND CIRCUIT CONFIGURATION

A. Design Calculations

For a ring oscillator with 3 inverters, the frequency of oscillation is given by:

$$f = \frac{1}{2 \times 3 \times \tau} = \frac{1}{6\tau} \quad (3)$$

Rearranging to find the propagation delay τ :

$$\tau = \frac{1}{6f} \quad (4)$$

The frequency f will be measured using an oscilloscope connected to the output of the ring oscillator. Once the frequency is obtained, it is substituted into the above equation to calculate the propagation delay τ of each inverter.

For example:

- If the measured frequency is $f = 10$ MHz, then:

$$\tau = \frac{1}{6 \times 10 \times 10^6} = 16.67 \text{ ns}$$

This method allows us to experimentally determine the propagation delay of the inverter gates used (74LS04 or CD4007) based on the measured output frequency of the oscillator.

B. Circuit Configuration

The circuit consists of:

- 3 inverter gates connected in a loop
- Output taken from any inverter stage
- Optional resistors or capacitors for shaping or measuring delay

74LS04: Connect pins of three inverters in a loop, power with +5V. **CD4007:** Use complementary NMOS and PMOS transistors to form three inverters. Power can range from +5V to +15V.

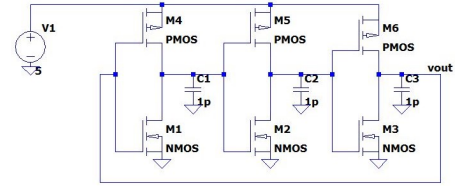


Fig. 3: Typical 3-stage ring oscillator configuration

V. PROCEDURE

A. Part A: Using 74LS04 (TTL Inverter)

- 1) Connect the V_{CC} pin (typically pin 14) of the 74LS04 IC to +5V and the GND pin (pin 7) to ground.
- 2) Select three inverters from the six available in the 74LS04.
- 3) Connect the output of the first inverter to the input of the second, and the output of the second to the input of the third.
- 4) Feed the output of the third inverter back to the input of the first inverter to form a closed loop (ring).
- 5) Observe the output waveform on an oscilloscope by probing the output of any one inverter.
- 6) Measure the frequency of the oscillation using the oscilloscope's frequency measurement tool.
- 7) Use the frequency value in the formula $\tau = \frac{1}{6f}$ to compute the propagation delay τ .

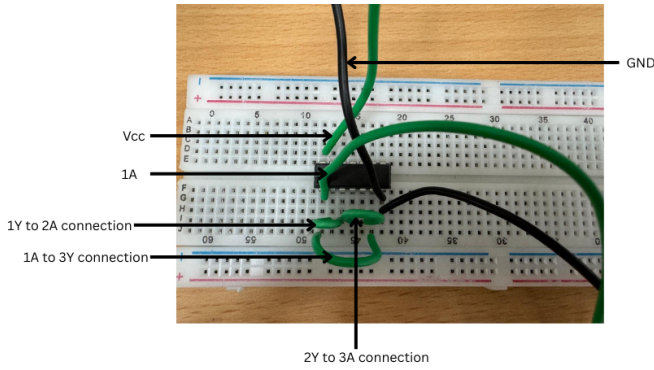


Fig. 4: Circuit implementation using 74LS04

B. Part B: Using CD4007 (CMOS Inverter)

- 1) Connect the V_{DD} pin (pin 14) of the CD4007 to +5V and the V_{SS} pin (pin 7) to ground.
- 2) Configure three CMOS inverters using the internal NMOS and PMOS transistors according to the CD4007 pinout.
- 3) Connect the three inverters in a ring configuration: output of one inverter to the input of the next, and the last inverter back to the first.
- 4) Observe the output waveform on an oscilloscope and measure its frequency.
- 5) Calculate the propagation delay using the measured frequency: $\tau = \frac{1}{6f}$.

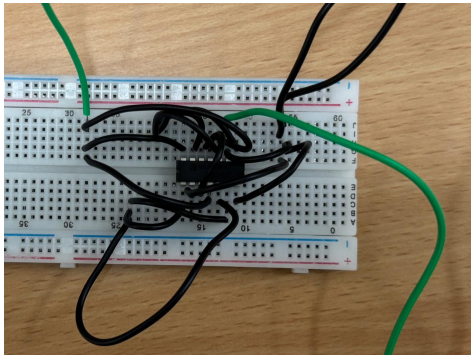


Fig. 5: Circuit implementation using CD4007

VI. RESULTS AND OBSERVATIONS

A. IC7404 Results

The ring oscillator was constructed using three inverters from the 74LS04 IC. The output waveform was observed on the oscilloscope, and the frequency was measured.

- Measured Frequency: **58 MHz**
- Theoretical Delay (τ):

$$\tau = \frac{1}{6f} = \frac{1}{6 \times 58 \times 10^6} \approx 2.9 \text{ ns} \quad (5)$$

- Observed waveform is nearly square with a consistent period, indicating stable oscillation.

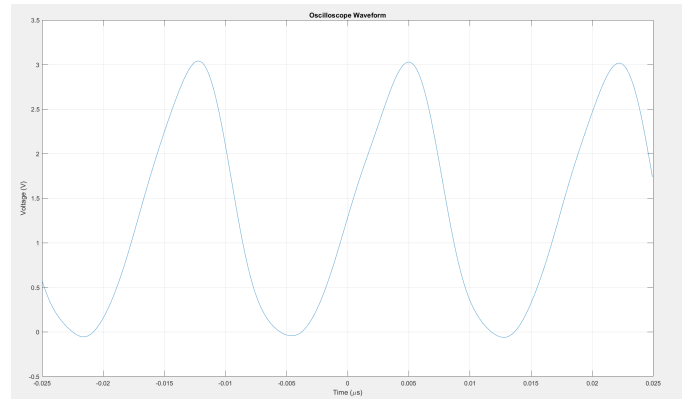


Fig. 6: Oscilloscope output waveform of IC7404-based ring oscillator.

B. CD4007 Results

The ring oscillator was also built using three CMOS inverters configured from the CD4007 IC. Frequency was similarly measured using an oscilloscope.

- Measured Frequency: **50 MHz**
- Theoretical Delay (τ):

$$\tau = \frac{1}{6f} = \frac{1}{6 \times 50 \times 10^6} \approx 2.8 \text{ ns} \quad (6)$$

- The waveform was slightly slower in transition due to the higher propagation delay of CMOS technology.

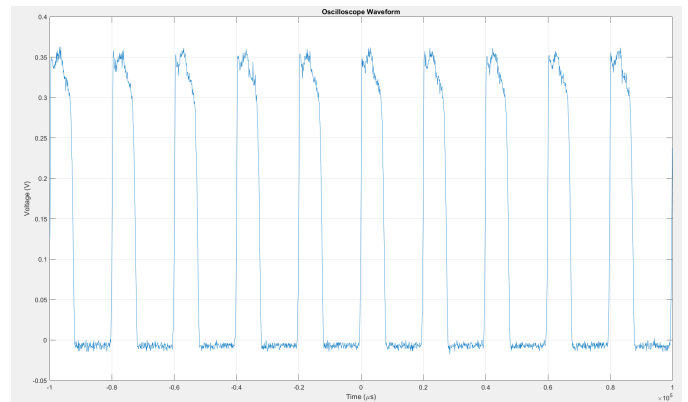


Fig. 7: Oscilloscope output waveform of CD4007-based ring oscillator.

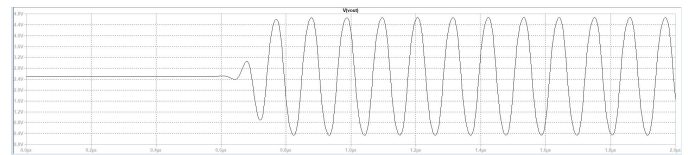


Fig. 8: LTSpice output waveform of CD4007-based ring oscillator.

C. IC7404 Bonus Results

The ring oscillator was constructed using five inverters from the 74LS04 IC. The output waveform was observed on the oscilloscope, and the frequency was measured.

- Measured Frequency: **58 MHz**
- Theoretical Delay (τ):

$$\tau = \frac{1}{6f} = \frac{1}{6 \times 58 \times 10^6} \approx 2.9 \text{ ns} \quad (7)$$

- Observed waveform is nearly square with a consistent period, indicating stable oscillation.

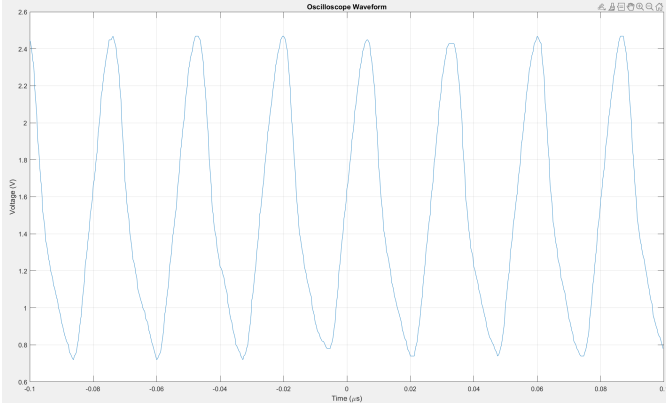


Fig. 9: Oscilloscope output waveform of IC7404-based ring oscillator.

VII. CONCLUSION

The ring oscillator experiment was successfully implemented using two types of logic families: TTL (74LS04) and CMOS (CD4007). The output frequency of oscillation was measured using an oscilloscope, and corresponding propagation delays were calculated using the standard ring oscillator formula. Results showed that the TTL-based oscillator (with 74LS04) achieved a higher frequency due to lower gate delay compared to the CMOS-based oscillator (CD4007), which exhibited slower operation due to higher propagation delay. The observed results align well with theoretical expectations, validating the working principles of ring oscillators.

This experiment reinforced the importance of propagation delay in high-speed digital circuit design and demonstrated how the type of logic family directly impacts signal timing and oscillation characteristics.

VIII. PRACTICAL CONSIDERATIONS

- Ensure that the power supply voltage levels are appropriate for each IC family: typically 5V for TTL (74LS04) and 5V–15V for CMOS (CD4007).
- Avoid floating inputs on unused gates to prevent noise and instability in oscillation.
- Use short and direct wiring on the breadboard to minimize parasitic capacitance and inductance, which could distort the waveform.
- Place the oscilloscope probe close to the output pin of the last inverter stage for accurate waveform capture.

- If the oscillator does not start, try using a high-value resistor (e.g., 10kΩ) for feedback or adding capacitive loading at the output to help sustain oscillation.
- Ensure all inverter stages are connected properly in sequence with correct orientation to maintain the required odd number of inverters.
- Be cautious of signal degradation due to loading effects if driving external circuits directly from the oscillator output.

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