

Miniproject 5 - Enhanced Waveform Generator

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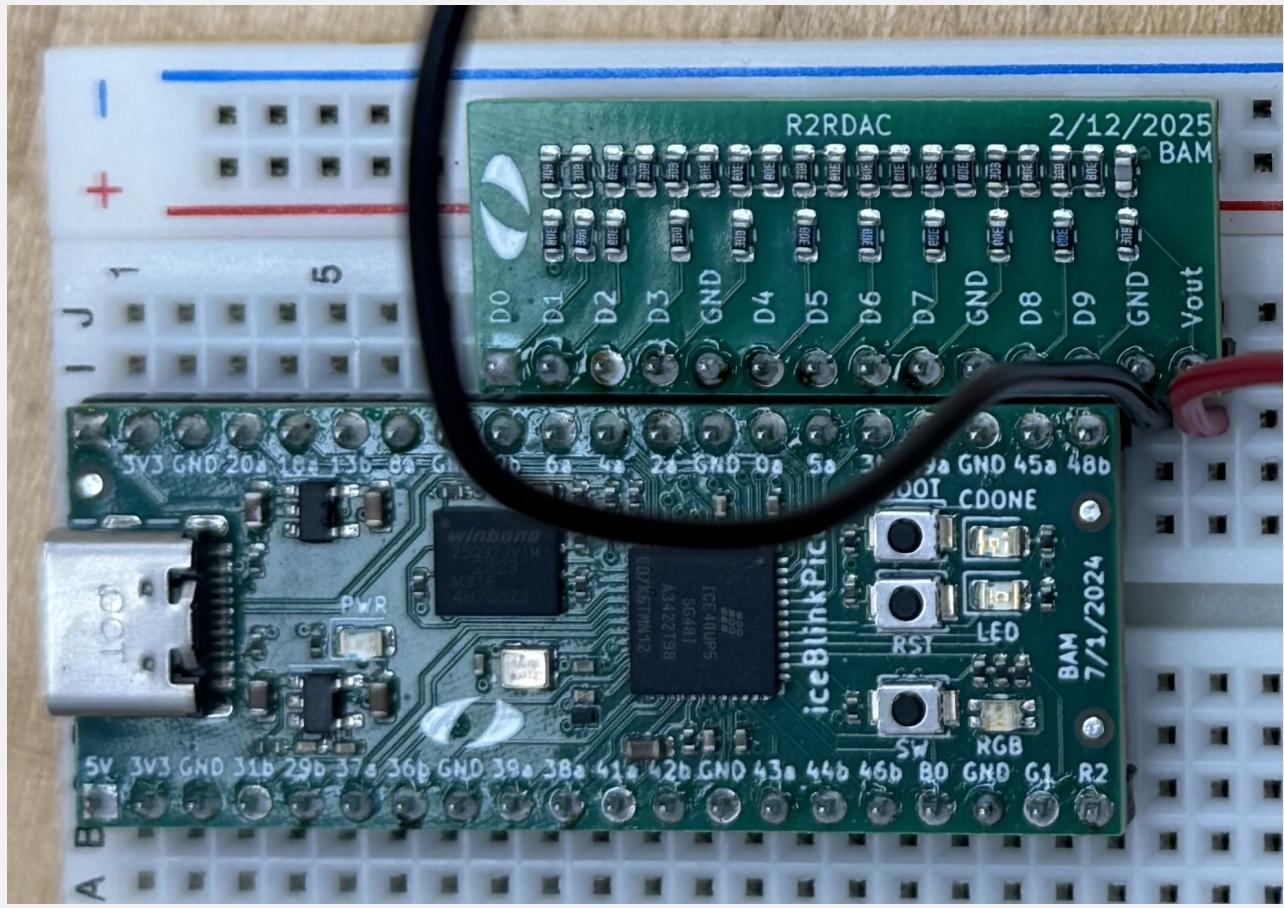
For the full assignment brief, see the original [MP5 proposal](#).

Repository: [Computer Architecture GitHub](#)

Circuit Design

This project expands the MP3 sine-wave by adding **square** and **triangle** outputs and on-board push-button control of frequency and waveform. A R-2R ladder DAC driven by the FPGA's GPIO produces the analogue waveform.

The physical setup on the *iceBlinkPico* breadboard is shown below:



Key design choices:

- **Quarter-wave memory** — a small on-chip block memory that stores 128 sine samples
- **32-bit phase accumulator** — updates every 12 MHz tick for ppm-level frequency resolution.
- **Button control** — BOOT cycles waveform (sine -> triangle -> square), SW cycles frequency (1 kHz -> 2 kHz -> 5 kHz -> 10 kHz).

How It Works

A 32-bit accumulator adds a selected *phase-increment* each 12 MHz clock cycle.

2. Address Split

The top 9 bits of the accumulator form:

- a 2 bit *quadrant* (phase[8:7])
- a 7 bit *quarter-address* (phase[6:0])

For quadrants 1 and 3, the quarter-address is reversed ([127 - phase\[6:0\]](#)).

3. Memory Lookup

The quarter-address indexes the 128-word memory initialized with the first quarter-cycle of a sine wave.

4. Waveform Reconstruction

- **Sine:** Add or subtract the memory output from mid-scale (512) based on the quadrant.
- **Triangle:** Use the top bits of the accumulator to form a linear up/down ramp.
- **Square:** Replicate the MSB of the accumulator across all 10 bits.

5. DAC Output

The resulting 10-bit [dac_out](#) drives the R-2R ladder to produce a 0-3.5 V analogue signal.

Symmetry Explanation

Using the symmetry of [sin\(θ\)](#) reduces the memory to one quarter-cycle. The four quadrants are handled as:

Quadrant	Angle Range	Addressing	Sign
Q0	0° – 90°	forward	+
Q1	90° – 180°	reverse	+
Q2	180° – 270°	forward	-
Q3	270° – 360°	reverse	-

SystemVerilog snippet:

```
module sine_gen(
    input logic      clk,
    input logic [8:0] phase,    // 9-bit input: 0-511
    output logic [9:0] out       // 10-bit output: centered around 512
);

    // Split phase into quadrant and index
    logic [1:0] quadrant;
    logic [6:0] quarter_address;
    logic [8:0] quarter_data;

    assign quadrant      = phase[8:7];
    assign quarter_address = (quadrant == 2'b01 || quadrant == 2'b11) ? (7'd127 -
```

```

phase[6:0]) : phase[6:0];

// Quarter-cycle memory lookup
memory_quarter #(
    .INIT_FILE("sine_quarter.txt")
) mem_inst (
    .clk(clk),
    .read_address(quarter_address),
    .read_data(quarter_data)
);

// Generate full-cycle sine from quarter lookup
always_comb begin
    case (quadrant)
        2'b00, 2'b01: out = 10'd512 + quarter_data; // positive half
        2'b10, 2'b11: out = 10'd512 - quarter_data; // negative half
        default:       out = 10'd512;
    endcase
end

endmodule

```

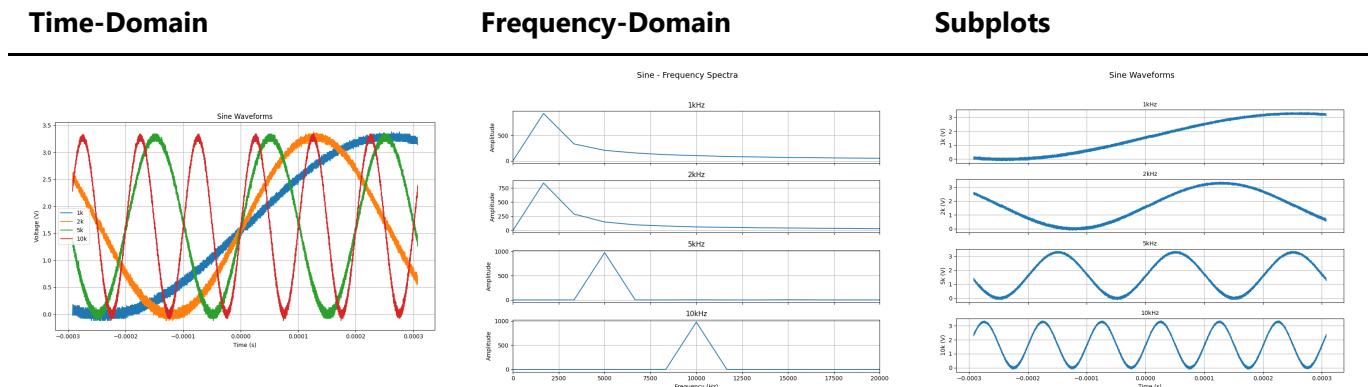
The same accumulator feeds a **triangle** generator (linear ramp using the MSBs) and a **square** generator (single MSB replicated).

Simulation Results

For each experiment three figures are generated:

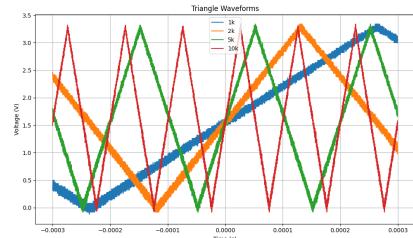
1. **Waveform Grid** – individual time traces for 1 kHz, 2 kHz, 5 kHz, 10 kHz.
2. **Frequency Spectra** – magnitude of the first 20 kHz of the FFT for each preset.
3. **Overlay Plot** – all four frequencies super-imposed to highlight phase/frequency scaling.

Sine

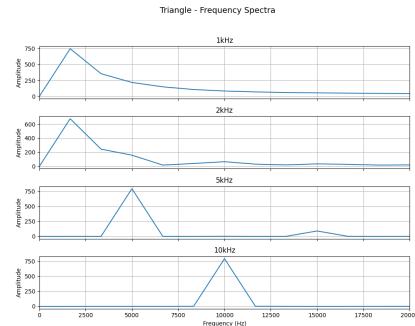


Triangle

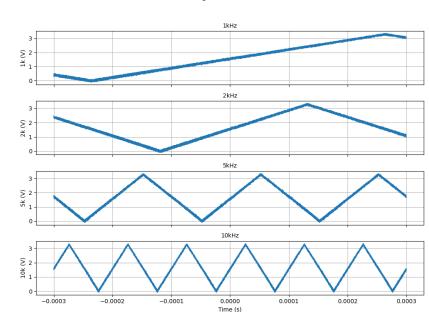
Time-Domain



Frequency-Domain

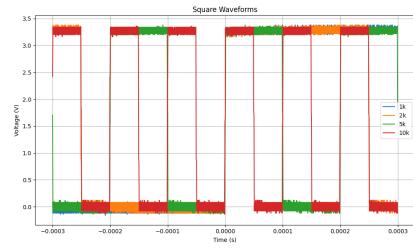


Subplots

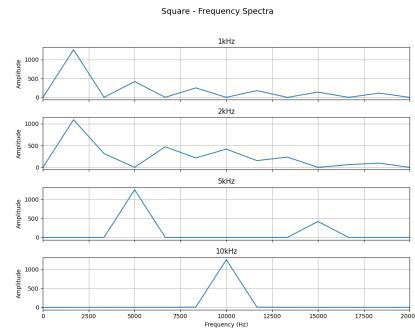


Square

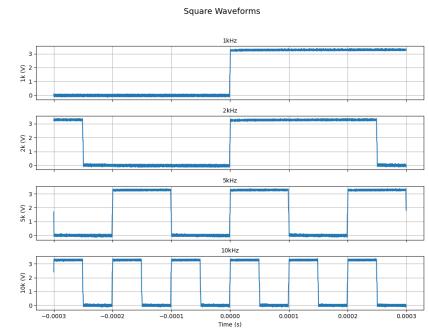
Time-Domain



Frequency-Domain



Subplots



Hardware Testing



Sine

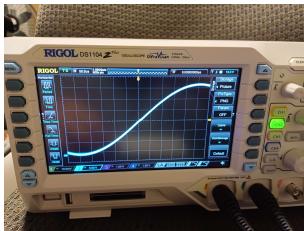
1 kHz

2 kHz

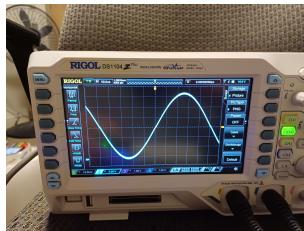
5 kHz

10 kHz

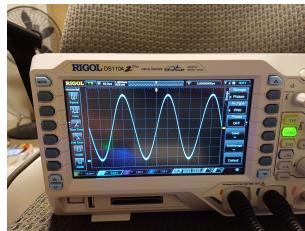
1 kHz



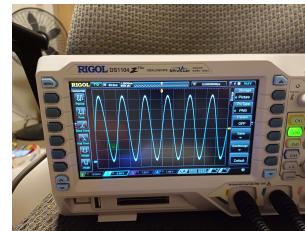
2 kHz



5 kHz



10 kHz



Triangle

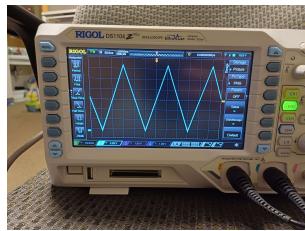
1 kHz



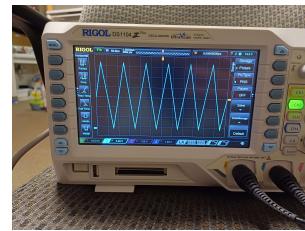
2 kHz



5 kHz

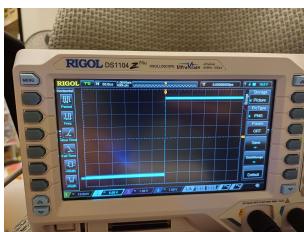


10 kHz

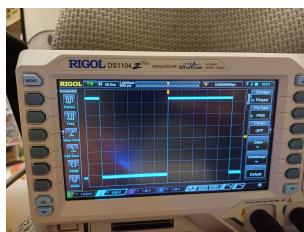


Square

1 kHz



2 kHz



5 kHz



10 kHz



Scope measurements show clean 0 to 3.5V output with peak-to-peak jitter < 10 mV. Measured frequencies match presets within $\pm 0.1\%$.

Conclusion

This design generates sine, triangle, and square waveforms with real-time selection of both frequency and waveform via on-board push-buttons. By storing only 128 samples for the sine lookup, it achieves a 75 % memory reduction compared to a full-cycle table, while the triangle and square outputs require zero stored samples by using simple combinational logic. Both simulation and bench testing verify correct waveform shapes and robust button-driven control.
