Analog Pong – functional description

Analog Pong is a traditional pong-style game implemented mostly with analog circuits. All video generation is analog and so is most of the game logic. There are some basic gate and flip-flop level digital circuits used, but I would not call this digital implementation.

Device plays three switch-selectable games:

- normal two-player tennis
- one-player tennis with automatic opponent
- simple solo-squash

It generates PAL-compatible black&white video signal. Sounds are fed directly to a speaker.

Various blocks of the schematic diagram are described in the following chapters. You should have the schematic handy, we will refer to it all the time.

Sync generators

Sync generators are implemented with a no-brainer 555-astable oscillators, using one 556 circuit IC1:

- IC1B generates horizontal sync, about 7 µs wide low-going pulses at 15.625 kHz.
- IC1A generates vertical sync, about 0.4 ms wide low-going pulses at 50 Hz.

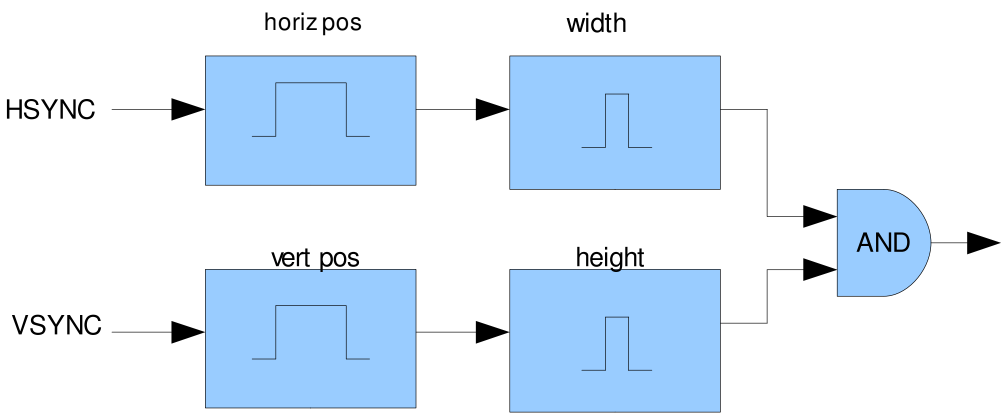
Sync frequencies can be adjusted with R5 and R6.

Spot generator principles

A spot generator is a basic building block in video generation. As the name implies, it can generate one spot on the screen. A spot is a white rectangular area on the black screen. Spot's width, height and vertical and horizontal position can be controlled.

Pong game uses four spot generators: ball, left paddle, right paddle and center line. First three use identical circuit, the center line generator is implemented with a bit different circuit.

Each spot generator consists of four monostables and an AND-gate, as you can see from the block diagram. Each monostable controls one of the spot's parameters: horizontal position, vertical position, width and height.



Position monostables are implemented with an analog comparator and width/height monostables with simple RC-circuit and a schmitt-trigger, which is included in the AND-gate. For ball and paddle generators, the position monostables are voltage-controlled, meaning their pulse width can be controlled with an external DC voltage.

Ball generator

Now let's look at the ball generator's inner workings:

Ball horizontal position is generated using comparator IC2B. When the low-going HSYNC-pulse comes, it discharges C6 via D1. Assuming the ball horizontal position control voltage CVBH is somewhere between 0 V and 5 V, as it usually is, the comparator becomes negatively biased and its output drops to low state.

After the sync pulse, C6 starts to charge through R8 and the voltage in comparator's positive input rises. After a while, this voltage exceeds the CVBH, comparator becomes positively biased and its output rises to high state. So, we got a low-going pulse which starts when the sync pulse comes and its length depends on the voltage CVBH.

While comparator's output was low, C7 discharged through R10 and R11. When the output rises high, the NAND-gate's input (IC3D, pin 12) rises also and the gate sees high-state in its input. Immediately C7 starts to charge through R9, R10 and R11 and the voltage in the gate's input starts dropping. After a short time, it goes below schmitt-trigger's threshold and the gate sees low-state again. The charging rate of C7, and thus the pulse width, can be adjusted with R11.

As a result of all this, we've got a single positive-going pulse for each HSYNC-pulse. The time between sync pulse and the output pulse can be controlled by varying the voltage CVBH. This time determines directly the spot's distance from the left edge of the screen. The output pulse width determines the spot's width on the screen and can be controlled by adjusting R11.

The IC2A with its surrounding passive components is used in the same way for ball's vertical position and height. The component values differ, because the time scale is different, but the principle is exactly the same. As a result, the voltage CVBV determines the spot's distance from the upper edge of the screen and the pulse width determines the spot's height.

Finally, the horizontal and vertical output pulses are NANDed together with IC2D, so the output signal BOUT is active (low) only when both horizontal and vertical pulses occur at the same time.

Paddle generators

The left and right paddle generators use the same circuit as the ball generator. The vertical control voltages CVLP and CVRP control the paddles' vertical position. The horizontal control voltages are produced by R35 and R36. With these trimmers the paddle horizontal positions can be adjusted. Corresponding output signals (active low) are LPOUT and RPOUT.

There is also an input signal WALL_EN in the left paddle generator. By taking this signal high, it forces the NAND-gate's vertical side input (IC3C, pin 9) to stay high. This effectively disables the vertical side of the spot generator and causes the LPOUT to activate on every horizontal line, spreading the spot vertically to whole screen height. This causes a vertical wall to appear instead of the left paddle during squash mode.

Center line generator

The center line generator works in the same principle as other spot generators but component level implementation is a bit different. The horizontal side monostables are formed from schmitt-inverters IC6A and IC6B, with corresponding passive components. R37 adjusts line's horizontal position and R40 adjusts line width.

The two horizontal side monostables alone would generate a continuous vertical line. In most pong games, the center line is dashed, so let's follow the tradition. This is done by modulating horizontal signal with a square wave, generated by IC6D. In principle it is a free running schmitt-trigger astable, but it is synced once per frame to VSYNC signal by discharging C20 through D8 during VSYNC pulse. This causes the dashing to stay in place vertically.

The NAND-function is done by IC7A, and it works the same way as in other spot generators. This NAND contains an additional input which is used as LINE_EN signal. By taking this signal low, it disables the whole generator, causing the center line to disappear completely during squash mode.

Video output stage

The outputs from the four spot generators are summed together by a four-input NAND IC7B. Because the spot generator outputs are active-low, the IC7B does effectively an OR-operation: if any of the spot generators is generating active (low) state, the IC7B output will be high.

NAND-gates IC8B and IC8C enable blanking of BOUT-signal before summing. By taking the signal HEDGE low, the ball spot can be blanked. This is used to blank the ball near left and right edges, because it sometimes disturbs the TV's horizontal synchronization, when the ball pulse is near the horizontal sync pulse.

Resistors R42, R43 and R44 adjust the voltage levels so that black level (IC7B output low) is about 0,7V and white level (IC7B output high) is about 1,4 V.

HSYNC and VSYNC pulses are summed (ORed) together with IC8D. They drive transistor T1, which forces the output signal to 0 V during sync pulses.

Note: This ouput stage does not work with a standard 75 Ω video input! This has too high output impedance. If standard video monitor is used, the output stage must be redesigned.

Ball horizontal movement

The voltage across C22 is used directly as ball generator's horizontal control voltage CVBH. Ball's horizontal direction is kept in the flip-flop IC11B. When the flip-flop is set, C22 charges slowly through R50 and R51 (ball speed control) and ball moves from left to right. When flip-flop is cleared, C22 discharges slowly, and ball moves from right to left.

The CVBH voltage is also monitored with comparators IC13A and IC13B. If CVBH drops below the limit set by R66, meaning the ball is over the left edge, output of IC13B drops to low state. Respectively, if CVBH rises over the limit set by R63, meaning the ball is over the right edge, output of IC13A drops to low state. Outputs are combined with AND-gate IC10A, which outputs the HEDGE signal and blanks the ball spot after it has gone over the left or right edge.

The ouputs from IC13A and IC13B also enable the hand controller serve switches. Pressing a serve switch while ball is on the playfield (between the edges) does nothing, because both comparators' outputs are high. This prevents players doing ”serves” in the mid-field. Only after ball has gone over the edge and the comparator's output has dropped, the corresponding serve switch can set or reset the ball direction flip-flop through AND-gates IC10C or IC10D.

In auto-play mode, the mode select switch short-circuits the left controller serve switch, causing the serve to happen immediately when the ball goes over the left edge and IC13B output drops.

Collisions between ball and paddles are detected with OR-gates IC9C and IC9D. If the ball spot generator (signal BOUT) and a paddle spot generator (signal LPOUT or RPOUT) are producing active (low) level at the same time, it means that the spots on the screen coincide at least partially. This produces collision signals LCOLL and RCOLL, which are used to set or reset ball direction flip-flop through AND-gates IC10C or IC10D. This causes the ball to change direction immediately when it hits a paddle.

Ball vertical movement

The voltage across C23 is used directly as ball generator's vertical control voltage CVBV. Ball's vertical direction is kept in the flip-flop IC11A. When the flip-flop is set, C23 charges slowly through R58 and R59 (ball angle control) and ball moves downwards. When flip-flop is cleared, C23 discharges slowly, and ball moves upwards.

The CVBV voltage is also monitored with comparators IC12A and IC12B. If CVBV drops below the limit set by R54, meaning the ball is over the upper edge, output of IC12A drops to low state, setting the flip-flop. Respectively, if CVBV rises over the limit set by R55, meaning the ball is over the lower edge, output of IC12B drops to low state, resetting the flip-flop. This keeps the ball always between the upper and lower edges.

Paddle movement

Left and right hand controllers contain potentiometers R69 and R13 that produce control voltages CVLP and CVRP for the paddle generators. Voltages are smoothed with C21 and C26.

In auto-play mode, the mode select switch connects the ball vertical control voltage CVBV to drive the CVLP instead of the controller potentiometer. This causes the left paddle to follow the ball's vertical position. As this would make an unbeatable opponent, the control voltage is connected through R67, which together with C26 produces an adjustable delay, when the paddle follows the ball. This makes the auto-player miss the ball sometimes.

Paddle direction detection

Normally ball's vertical direction does not change between the lower and the upper edges.

This means that ball always bounces from the paddle as in basic physics: the angle of reflection equals the angle of incidence. The paddle movement detector circuit is used to change this. If the paddle is moving when the collision between ball and paddle occurs, the ball's direction is set equal to paddle's direction, so it may bounce the ball back to the direction where it came from.

The left paddle control voltage CVLP is monitored with comparators IC15D and IC15A. IC15D outputs high state when CVLP is rising and IC15A outputs high state when CVLP is falling. Similar monitoring is done for the CVRP with comparators IC15C and IC15B.

Multiplexer IC16 selects between left and right paddles: when ball is moving left, we are interested only in the left paddle and when it is moving right, we are interested only in the right paddle. Also only the expected collision signal LCOLL or RCOLL is selected respectively. Signal HMUX from the ball horizontal direction flip-flop is used as the selection signal.

OR and AND-gates IC9B, IC17B and IC9A implement rest of the logic. OR-gate IC9B combines the two signals ”paddle is moving up” and ”paddle is moving down”, produced by the comparators, to one signal ”paddle is moving”. Inverter IC17B and OR-gate IC9A combine this with the collision signal to get the signal ”paddle is moving and is touching the ball”. This is used to clock the ball vertical direction flip-flop. The data that is clocked in is the signal ”paddle moving down”. As a result, the paddle's direction is stored in the flip-flop at the moment the ball touches the paddle.

Sound generator

The game generates simple ping-pong sounds every time the ball bounces from a paddle or ball is served; in other words, every time the ball changes horizontal direction.

Signal HMUX from the ball horizontal direction flip-flop is brought to monostable flip-flops IC18A and IC18B. IC18A trigs at rising edge (when ball changes direction from right to left) and IC18B at falling edge (when ball changes direction from left to right). The monostables' pulse lengths are a few milliseconds.

Schmitt-inverter oscillators IC17C and IC17A generate square waves, whose frequencies can be adjusted with R91 and R89. The oscillators are gated from monostables' outputs, so that they oscillate only when the corresponding monostable is outputting its pulse. As a result, we get short square wave bursts at each edge of HMUX.

The square wave bursts are summed with IC17D and fed to transistor T2, which drives speaker directly through volume control R92.