

PAL-1 Digital Complex Sound Generator

Plastic Objects Limited

Published by **Plastic Objects Limited**
Woodbridge, UK

August 2022

Disclaimer

Every effort has been made to ensure the accuracy of the information contained in this document. The information presented within is accurate at the time of publication. Whilst every effort is made to provide accurate information, no warranty or fitness is provided or implied, and the authors and publishers shall have neither liability nor responsibility to any person or entity with respect to any loss or damages arising from its use.

All trademarks, logos and brand names are the property of their respective owners. All company, product and service names mentioned in this document are for identification purposes only. Use of these names, trademarks and brands does not imply endorsement.

PAL-1 and the PAL-1 logo used with kind permission of Liu Ganning.

Contents

| | |
|--|-----------|
| Introduction | v |
| 1 Getting Started | 1 |
| 2 Using the PAL-1 Digital Complex Sound Generator | 3 |
| 3 Sample Code | 7 |
| A SN76489 Data Formats | 11 |
| B Schematic Diagram | 15 |
| C Board layout | 17 |
| D Bill of Materials | 19 |

Introduction

The PAL-1 Digital Complex Sound Generator is an expansion module for the PAL-1 system¹, based on the Texas Instruments SN76489 Digital Complex Sound Generator (DCSG)² and was inspired by a Ciarcia's Circuit Cellar project³.

The SN76489 DCSG was used in a range of arcade games, game consoles, and home and business computers from the late 1970s and throughout the 1980s. Notable systems using discrete SN76489 ICs include the ColecoVision games console and BBC Micro home computer. Others, such as the SEGA Mega Drive, include the SN76489 in their Video Display Processor (VDP) or used SN76489 clones, for example the Tandy 1000 and IBM PCjr.

The SN76489 provides three programmable tone generators and a noise source. The signals generated by the tone generators and noise source are mixed in the IC and passed to an output buffer. Since the maximum drive of the SN76489 output pin is just 10mA, the PAL-1 Digital Complex Sound Generator includes a simple audio power amplifier circuit to allow a speaker to be directly connected.

¹Liu Ganning, 'PAL-1 Microcomputer User Manual', 2020, http://pal.aibs.ws/assets/PAL_en.pdf [accessed 21 July 2022].

²The EngineeringStaff of TEXAS INSTRUMENTS Semiconductor Group, 'SN76489AN' (TEXAS INSTRUMENTS, N.D.)

³Ciarcia, Steve, 'Add Programmable Sound Effects to Your Computer', Byte, 7.7 (1982), 60–72

1. *Getting Started*

Board assembly

Before assembling your PAL-1 Digital Complex Sound Generator board check the package contents against the Bill of Materials on page 19, and contact your distributor as soon as possible if any items are missing.

No specialist tools are required for assembling the board, though care must be taken when handling ESD sensitive components, especially the ICs. Before inserting the ICs into their sockets, check the board for dry joints and solder bridges.



To prevent damage to your system, *always* power off your PAL-1 before installing or removing the PAL-1 Digital Complex Sound Generator board. Ensure that the pins are correctly aligned when inserting the board into the PAL-1 motherboard or when directly connecting it to the PAL-1 expansion port using a 40-pin IDC cable.

Audio output

The PAL-1 Digital Complex Sound Generator incorporates an LM386 audio power amplifier to allow an 8Ω speaker to be directly connected. To connect a speaker or external amplifier use a cable with a 3.5mm mono audio jack. Sound will be heard on one channel only when stereo speakers or a stereo amplifier are used.

Audio volume can be controlled by adjusting the potentiometer (RV1). Refer to *Attenuation* on page 12 for details on setting audio volumes of individual channels. **Note that on power-up the SN76489 registers will contain random values, meaning that random noise may be heard until the attenuation registers are updated.**

I/O address configuration

The SN76489 DCSG has an 8-bit write only data bus, which is memory mapped on the PAL-1 system. The address at which it is mapped can be configured using jumper JP1, as shown in Table 1.1. Note that these addresses are *not* mirrored at \$FEEE or \$FEEF.

The default address (and the address used in all examples in this manual) is \$16EE (5870 decimal). In situations where multiple sound generator boards are installed in the same PAL-1 system, each board must have a unique address.

| JP1 pins | Address |
|----------|---------|
| 1-2 | \$16EE |
| 2-3 | \$16EF |

Table 1.1: I/O address configuration

2. *Using the PAL-1 Digital Complex Sound Generator*

SN76489 internals

The SN76489 contains 8 internal registers which control the volume and frequencies of each of its three tones and the volume, type and shift-rate of the noise generator. Register values are changed by writing to the SN76489 8-bit data bus, which on the PAL-1 is memory mapped at either \$16EE or \$16EF.

Each tone generator requires 10 bits of information to set the frequency and 4 bits of information to set the attenuation. Since the SN76489 bus is 8 bits wide, frequency updates require double byte transfers, whilst changing attenuator values is achieved by writing single bytes. When writing data to the SN76489 the most significant bit (msb) of the first byte, the 'latch and data' byte, is always 1. For register updates that require a second byte, a 'data' byte, the msb is always 0.

Latch and data bytes

A 'latch and data' byte is identified by its first bit, which is always 1. This is followed by bits indicating the register (r) to be updated, composed of the destination channel (r0 & r1) and the register type (r2). The final bits (d0 thru d3) are the actual data to be written to the relevant register. When writing to the noise source register, which requires only 3 bits of data, the highest bit (d0) is discarded.

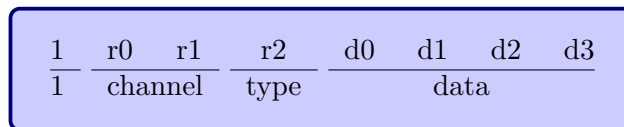


Figure 2.1: Latch and data byte format

Refer to Table 2.1 for details of the channel and type bits (r0-r2).

| r0 | r1 | channel | r2 | type |
|----|----|---------|----|--------------|
| 0 | 0 | tone 1 | 0 | tone / noise |
| 0 | 1 | tone 2 | 1 | attenuation |
| 1 | 0 | tone 3 | | |
| 1 | 1 | noise | | |

Table 2.1: Latch and data byte register (r) bits

Data bytes

The first bit of a 'data' byte is 0. Since frequency data consists of 10 bits, with the first 4 bits specified in the 'latch and data' byte, only 6 bits of frequency information are required in a 'data' byte (as shown in Figure 2.2).

Data is written to the register most recently latched using a 'latch and data' byte. This means that the lower 6 bits of a frequency can be updated without re-specifying the relevant tone register, for example for frequency sweeps.

Note that data is not ignored when the most recent register latched was something other than a tone frequency register. Rather, the number of bits required for the relevant type will be written to the latched register. For example, audio volume can be faded in or out by consecutive data writes to an attenuation register.

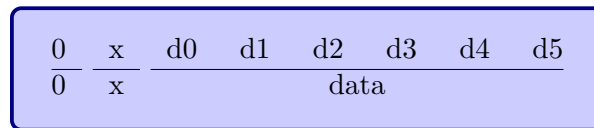


Figure 2.2: Data byte format

Calculating frequency values

The SN76489 relies on an external clock signal to generate sounds, which On the PAL-1 Digital Complex Sound Generator board is 2Mhz. The external clock is divided by 16 to arrive at an internal clock of 125Khz.

Each tone and the noise generator has a 10 bit counter and an output bit. When not 0, each counter is decremented at the rate of the internal clock. When a counter reaches 0, the output bit for the relevant tone or the noise generator is flipped from 0 to 1 (or vice versa) and the counter is reset to the value currently in corresponding register. The result is a square wave, with a wavelength of double the register value. Its frequency can be calculated using the following formula

$$f = \frac{N}{32n}$$

where N = reference clock in Hz (i.e. 2Mhz)

n = 10-bit binary counter value

For example, to set tone generator 1 to a frequency of 466.164Hz ($A\#_4$), first find I :

$$I = \frac{N}{32f} = \frac{2,000,000}{32 * 466.164} = 134.073$$

Since I must be an integer value, it is rounded down to 134. Next, I must be converted to a 10-bit binary frequency value f as shown in Figure 2.3¹:

| f0 | f1 | f2 | f3 | f4 | f5 | f6 | f7 | f8 | f9 |
|----|----|----|----|----|----|----|----|----|----|
| 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |

Figure 2.3: 446Hz 10 bit frequency value

The 10 bits of frequency data are written to the SN76489 split across 2 bytes. The first byte includes register details (bits r0-r2) and 4 bits of data (f6-f9). The second byte contains the remaining 6 bits of data (f0-f5).

Therefore to set tone generator 2 at 446Hz, the value of the first byte to be written is 166, followed by a second byte with a value of 4 (see Figures 2.4 and 2.5).

Finally, for sound to be heard the attenuation weight of the tone needs to be set. This requires writing a single byte containing the tone register address and attenuation weight. For example, setting the attenuation of tone 2 to 10dB requires a 'latch and data' byte value of 181 (see figure 2.6).

When using BASIC, these values can be written to the SN76489 using POKE statements:

```

100 N=5870:REM      SN76489 BASE ADDRESS
110 POKE N,166:REM  TONE 2 FREQ REG AND FIRST 4 BITS OF FREQ DATA
120 POKE N,4:REM    REMAINING 6 BITS OF FREQ DATA
130 POKE N,181:REM  TONE 2 ATTENUATION REG AND ATTENUATION WEIGHT

```

¹The example calculations shown here follow the bit hierarchy as used in the original SN76489 documentation as published by Texas Instruments in which the most and least significant bits are transposed.

| 1 | r0 | r1 | r2 | f6 | f7 | f8 | f9 |
|---|----|----|----|----|----|----|----|
| 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 |

Figure 2.4: Latch and data byte to set tone 2 at 446Hz

| 0 | x | f0 | f1 | f2 | f3 | f4 | f5 |
|---|---|----|----|----|----|----|----|
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

Figure 2.5: Data byte with lower bits of 466Hz frequency

| 1 | r0 | r1 | r2 | a0 | a1 | a2 | a3 |
|---|----|----|----|----|----|----|----|
| 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 |

Figure 2.6: Latch and data byte setting tone 2 attenuation at 10dB)

Limitations

It takes the SN76489 approximately 32 clock cycles to read data from the bus. In the current implementation the SN76489 READY signal has been left unconnected, which means that it is not possible to use this signal for synchronisation purposes. For reliable operation it is recommended to leave a gap of at least $16\mu\text{s}$ between writes. This should not be an issue when using high level languages (such as BASIC). However, when using assembly language, care must be taken when writing data to the DCSG to ensure no data is lost.

3. *Sample Code*

Programming the PAL-1 Digital Complex Sound Generator's SN76489 simply requires the ability to write to the mapped I/O address. Many programming languages provide statements to achieve this, including the POKE statement in BASIC and C! in Forth.

Note that all examples included here use the default I/O address (ie. \$16EE, 5870₁₀).

Further examples may be found on Github at <https://github.com/dimitrit/pal1dcsg>.

BASIC

The following 'tone test' example was taken from the 'Add programmable Sound Effects to Your Computer' article in the July 1982 issue of BYTE magazine (pp. 60-72). Note that since the PAL-1 uses memory mapped i/o, all OUT statements have been replaced with POKE statements.

```
100 REM      ****   SN76489A TONE TEST   ****
110 N=5870:REM SOUND GENERATOR BASE ADDRESS
120 POKE N,159:POKE N,191:POKE N,223:POKE N,255:REM CLEAR OUTPUTS
125 REM TONE OUTPUT IS CLOCK/32*I -- ENTER I TO TEST TONE OUTPUT
130 PRINT "DIVIDER VALUE":INPUT I
150 B=INT(I/16)
160 A=I-B*16+128
200 POKE N,A:POKE N,B:REM SET 2 BYTE TONE VALUE ON 76489A
220 POKE N,144:REM TURN ON TONE 1 OUTPUT
230 FOR X=0 TO 1000:NEXT X:REM DELAY
240 GOTO 120
```

Listing 3.1: Tone test

6502 assembly language

As it is not possible to check whether the SN76489 has finished reading its input buffer, care must be taken to not overflow this buffer when using

assembly language. In the example below the PAL-1 RIOT timer is used to wait a number of milliseconds between writes. If the RIOT timer is not available, an appropriate delay must be ensured by other means, for example using NOP statements in a loop.

```

;          **** GREENWICH TIME SIGNAL ****
;
; Plays the BBC radio hourly Greenwich time signal pips.
;
; Note that in addition to the PAL-1 Digital Complex Sound Generator card,
; this example requires the RIOT expansion module.
;

sndio      = $16ee          ; SN76489 i/o address
clk1kt     = $1707          ; RIOT timer @ 1024T increments

; Set attenuation
setattn    .macro c, w          ; c=channel (0-3), w=weight (0-15)
            lda #((\c<<1)+9)<<4)+\w
            jsr sendbyte
            .endm

; Set frequency
setfreq    .macro c, f          ; c=channel (0-3), f=freq (0-1023)
            lda #((\c<<1)+9)<<4)+(\f&15)
            jsr sendbyte
            lda #(\f>>4)
            jsr sendbyte
            .endm

; Delay
delayms    .macro n              ; n=delay in ms
            lda >(\n)
            sta duration
            lda <(\n)
            jsr delay
            .endm

* = $60

duration   .byte 0              ; delay duration

* = $200

.for c:=0, c<4, c+=1          ; silence tones 1-3 and noise
setattn c, 15
.next

setfreq 0, 63                  ; set tone 1 to 1KHz

ldx #5                          ; play 5 pips
pip        setattn 0, 5          ; set tone 1 attenuation to 10dB

```

```

delayms #100           ; play pip for 100ms
setattn 0, 15          ; silence tone 1
delayms #900           ; wait 900ms
dex
bne pip                ; done playing pips?

setattn 0, 5           ; play final pip for 500ms
delayms #500           ; wait 500ms
setattn 0, 15          ; silence tone 1

brk                    ; and done!

sendbyte               sta sndio           ; (2T + 6T) + 3T send byte to SN76489
                        rts                ; 6T (17us in total incl. lda/jsr)

delay                  sta clk1kt          ; wait A milliseconds
delayloop              bit clk1kt
                        bpl delayloop      ; RIOT timer not done
delaynext              dec duration        ; ms wait remaining?
                        bmi senddone       ; no, all done
                        lda #255           ; yes, wait another 255ms
                        bne delay          ; and loop again
senddone               rts

                        .end

```

Listing 3.2: Greenwich time signal pips

A. *SN76489 Data Formats*

When sending data to the SN76489 the most significant bit (msb) of the 'latch and data' byte (typically the first or only byte written to the SN76489 DCSG) is always 1. Where additional data is required (typically the second byte written), the msb of the 'data' byte is always 0.

The register (r) bits in the 'latch and data' byte determine both the channel being targetted and the type of data being sent (see Table A.1). Once a target has been latched, any subsequent 'data' bytes will affect that target.

| r0 | r1 | channel | r2 | type |
|----|----|---------|----|--------------|
| 0 | 0 | tone 1 | 0 | tone / noise |
| 0 | 1 | tone 2 | 1 | attenuation |
| 1 | 0 | tone 3 | | |
| 1 | 1 | noise | | |

Table A.1: Latch and data byte register (r) bits

Frequency

Frequency updates require 2 bytes, the first indicating the channel and top 4 bits of frequency data with the remaining frequency data in the second byte. See page 2 for details on calculating frequency data.

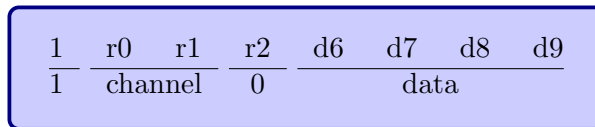


Figure A.1: First byte of frequency update

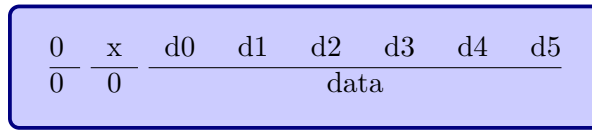


Figure A.2: Second byte of frequency update

Attenuation

Attenuator updates require a single byte, indicating both the channel and attenuation weight (see Table A.2 for weight values).

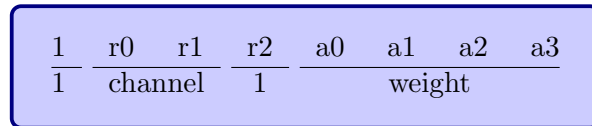


Figure A.3: Attenuator update

| a0 | a1 | a2 | a3 | weight (dB) |
|----|----|----|----|-------------|
| 0 | 0 | 0 | 0 | 0 dB |
| 0 | 0 | 0 | 1 | 2 dB |
| 0 | 0 | 1 | 0 | 4 dB |
| 0 | 1 | 0 | 0 | 8 dB |
| 1 | 0 | 0 | 0 | 16 dB |
| 1 | 1 | 1 | 1 | off |

Table A.2: Attenuation weight bits

On power-up the SN76489 registers will contain random values, meaning that random noise may be heard before any attenuation registers are written to.

The following BASIC statements may be used to silence all channels:


































```

100 N=5870:REM      SN76489 I/O ADDRESS
110 POKE N,159:REM  Tone 1 off
120 POKE N,191:REM  Tone 2 off
130 POKE N,223:REM  Tone 3 off
140 POKE N,255:REM  Noise off

```

Listing A.1: Clear SN76489 attenuation registers

Alternatively, to silence all channels using the KIM monitor:

| <i>Press keys</i> | <i>See printed</i> |
|---|--------------------|
|  | KIM |
|     | xxxx xx |
|  | 16EE |
|    | 16EE 00 |
| | 9F. |
| | 16EF xx |
|     | 16EE |
|  | 16EE 00 |
|    | BF. |
| | 16EF xx |
|     | 16EE |
|  | 16EE 00 |
|    | DF. |
| | 16EF xx |
|     | 16EE |
|  | 16EE 00 |
|    | FF. |
| | 16EF xx |

Noise source

Noise source updates require a single byte indicating the noise channel, noise type, and shift rate (see Table A.3 for details on shift rates).

| | | | | | | | |
|---|----|----|----|---|-----------------|------------|-----|
| 1 | r0 | r1 | r2 | x | nt ¹ | nf0 | nf1 |
| 1 | 1 | 1 | 0 | 0 | 0 or 1 | shift rate | |

¹ Noise type: 0 = periodic noise, 1 = white noise

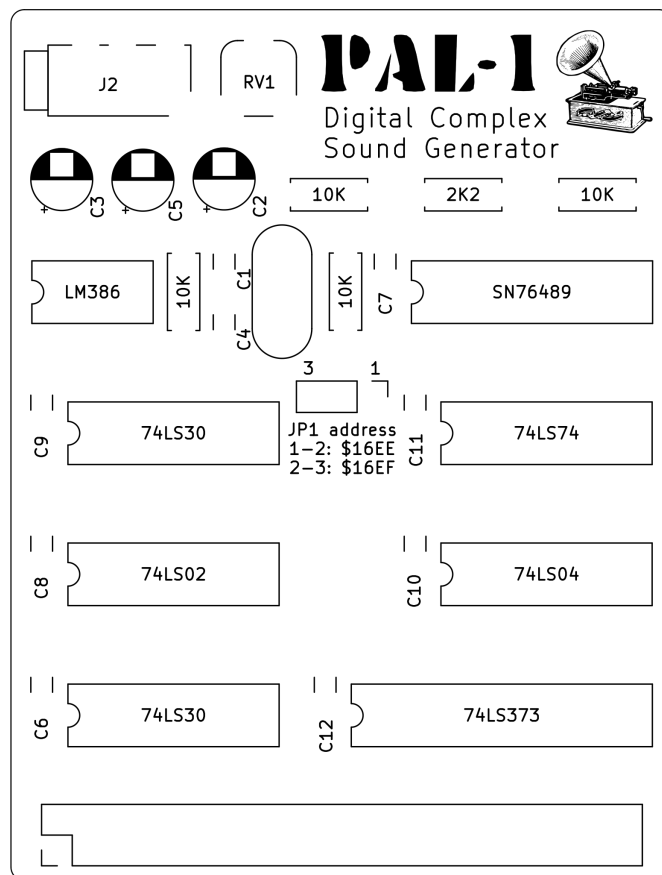
Figure A.4: Noise update

| nf0 | nf1 | shift rate |
|-----|-----|-------------------------|
| 0 | 0 | n/512 |
| 0 | 1 | n/1024 |
| 1 | 0 | n/2048 |
| 1 | 1 | tone generator 3 output |

Table A.3: Shift rates

B. *Schematic Diagram*

C. *Board layout*



D. *Bill of Materials*

| Part | Qty | Value | Description |
|--------------|-----|---------|---|
| C1,C4,C6-C12 | 9 | 0.1uF | Unpolarized capacitor |
| C2 | 1 | 10uF | Polarized capacitor |
| C3, C5 | 2 | 220uF | Polarized capacitor |
| J1 | 1 | | Connector, double row, 02x20 |
| J2 | 1 | | Audio Jack, 3.5mm |
| JP1 | 1 | | Jumper, 3-pole, pins 1+2 closed/bridged |
| R1 | 1 | 2K2 | Resistor |
| R2 - R5 | 4 | 10K | Resistor |
| RV1 | 1 | 10K | Potentiometer |
| U1 | 1 | SN76489 | Digital Complex Sound Generator |
| U2, U4 | 2 | 74LS30 | 8-input NAND |
| U3 | 1 | 74LS02 | Quad 2-input NOR gate |
| U5 | 1 | 74LS373 | 8-bit Latch, 3-state outputs |
| U6 | 1 | 74LS04 | Hex Inverter |
| U7 | 1 | 74LS74 | Dual D Flip-flop, Set & Reset |
| U8 | 1 | LM386 | Low Voltage Audio Power Amplifier |
| Y1 | 1 | 4.0Mhz | Two pin crystal |
| PCB | 1 | | PAL-1 Digital Complex Sound Generator PCB |

Table D.1: PAL-1 Digital Complex Sound Generator V1.0A components