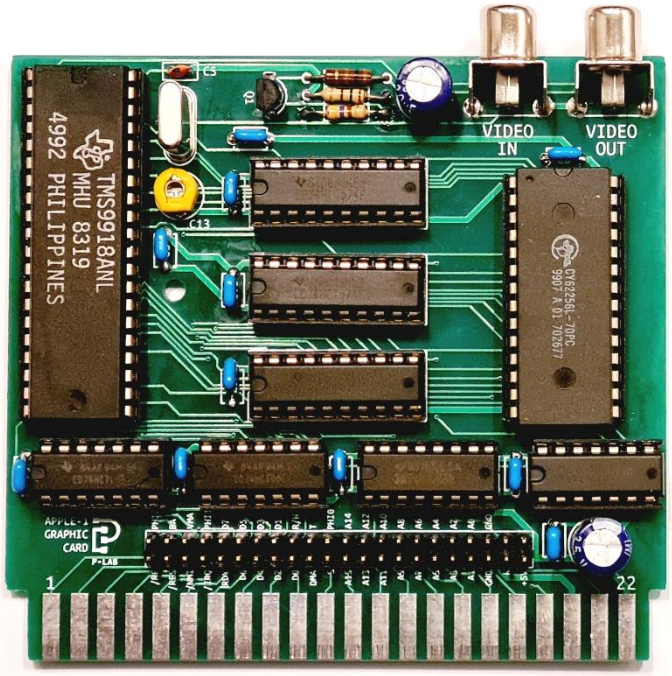
APPLE-1 GRAPHIC CARD

V0.4

Apple-1 Graphic Card it's an electronic board which allows you to add graphic capabilities to your Apple-1 computer.

This document contains:

1. Project description
2. Risk of electrostatic discharges
3. Installation of the card
4. Memory mapping
5. Technical notes about the hardware
6. Management software
7. Bibliography



Picture above is for illustration purpose only.
Actual product may vary due to due to product enhancement or availability of components.

1. PROJECT DESCRIPTION

The board is based on the well-known **Texas Instruments TMS9918A** Video Processor (or VDP), released in 1979 and used on computers and consoles of that period and later, such as ColecoVision, MSX1, TI99/4A etc.
Its standard interfacing mode, as well as independent Video RAM (separate from the system RAM) make this chip particularly suitable for use on Apple-1 because it does not subtract resources to it.
The graphic features are equally remarkable (from Wikipedia):

- **Mode 0 (Text):** 240×192 pixels total, as 40×24 characters, pulled from 1 character set of 256 6×8 pixel characters. The entire character set has a 2-color limitation. This mode doesn't support sprites.
- **Mode 1 (Graphic 1):** 256×192 pixels total, as 32×24 characters, pulled from 1 character set of 256 8×8 pixel characters. Each group of 8 characters in the character set has a 2-color limitation. For example, the characters "0" through "7" will all have the same color attributes.
- **Mode 2 (Graphic 2):** 256×192 pixels total, as 32×24 characters, pulled from 3 character sets of 256 8×8 pixel characters. Each 8-pixel-wide line of a character in the character sets has a 2-color limitation. This mode provides a unique character for every character location on screen, allowing for the display of bitmapped images.
- **Mode 3 (Multicolor):** 256×192 pixels total, 64×48 changeable virtual pixels, as 32×24 "semi-graphics" characters. These semi-graphics are defined in a special character set of 256 characters defined by 2×2 "fat-pixels". There are 4×4 pixels in each fat-pixel, but the pixels within a fat-pixel cannot be individually defined, although each fat-pixel can have its own color, hence the name of this mode (Multicolor). This mode is very blocky, and rarely used.

In modes 1, 2 and 3 the VDP can handle up to 32 Sprites, albeit with limitations. For more information see the original reference document, cited in the bibliography.

The video output of the graphics card is separate and independent from the original Apple-1, so it will be necessary to provide a second multistandard monitor, **compatible with video composite signal and NTSC color encoding**. *If the monitor is not compatible, the images will appear in black and white.*

From the point of view of the code needed to make it work, several options have been arranged, which will be described below.

Note that this project is not intended to have any commercial relevance, but simply to be an educational *Proof of Concept.*

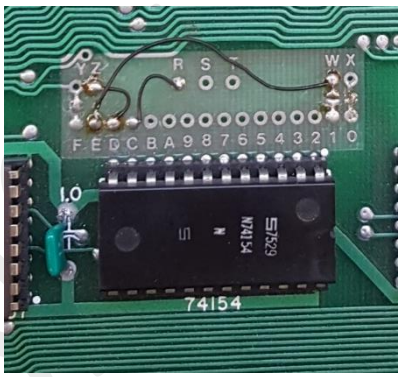
2. DAMAGES FROM ELECTROSTATIC DISCHARGES

Apple-1 Graphic Card is sensitive to static electricity, just like your Apple computer, and may be damaged by it. Before any operation on your devices, you must discharge the static electricity accumulated by your body and prevent it from building up again.
We do not accept any responsibility for damage, even serious or fatal, caused to people / things / intellectual property during the installation or use of this device.

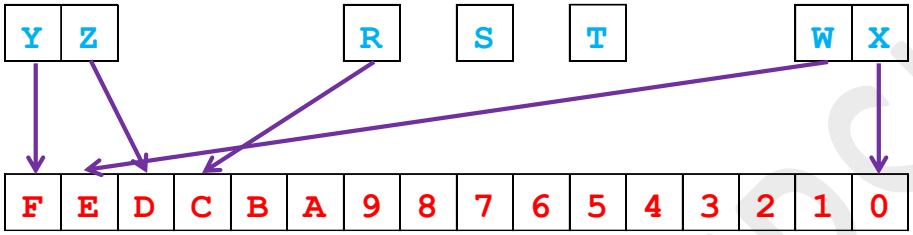
3. INSTALLATION OF THE CARD ON THE APPLE-1 COMPUTER

3.1 INITIAL CHECKS

Apple-1 must be set up with the configuration “WITH ACI”, with the following connections in the CHIP SELECT area:

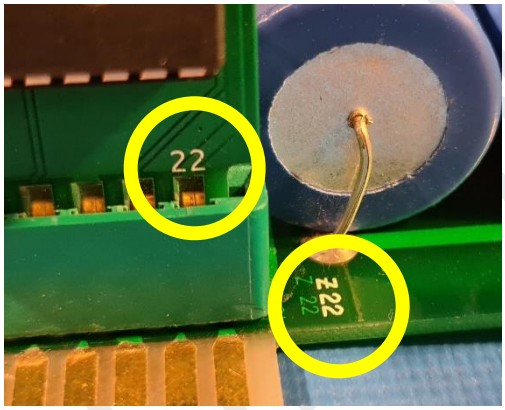


CONFIGURAZIONE CON ACI



The diagram and the picture show the necessary connections.
These wirings are quite standards among all the all Apple-1 computers, both Originals and Replicas.
There is no need to other dedicated wirings.

3.2 INSTALLATION



The card must be inserted as shown in the picture:

The number "22" on the card and the number "22" on the motherboard must be on the same side.

The number "22" on the card must therefore face the outer side of the Apple-1 motherboard.

WARNING: Switching on the computer with the card oriented incorrectly **INSTANTLY DAMAGES** the computer and the card itself.

If you use a BUS EXTENDER, be aware that unexpected behavior such as sudden locks or memory corruption may occur. If this happens, try to change/swap card positions. This can randomly happen also with Juke-Box or CFFA1 expansion cards. Error-free interaction between the cards and computer cannot be guaranteed.

4. MEMORY MAPPING

The TMS9918A needs only two memory addresses to program all of its many registers. They were therefore spilled from the memory segment $C000-$CFFF, partially occupied by the ACI, according to the following scheme:

C000-CFFF	C000-C3FF	1	ACI
	C400-CBFF	2 kB	UNALLOCATED
	CC00-CFFF	1 kB	TMS9918A

As you can see, the 4 kB of the $C000-$CFFF range has been divided into three parts. The first block was left dedicated to the Cassette Interface (ACI) for compatibility reasons. The next 2kB were not allocated.

Finally, an entire kB of addresses was dedicated to the actual VDP.

Note how the entire 1kB range is fully committed for only two addresses. This is clearly an inefficiency point driven by keeping the hardware as simple as possible.

The memory addresses dedicated to the VDP are therefore mapped as follows:

TMS9918 REGISTER	HEX ADDR	DEC ADDR	INTEGER BASIC ADDR
0	CC00	52224	-13312
1	CC01	52225	-13311

For the meaning and use of the many registers, please refer to the official documentation and the extensive literature available on the subject.
Because of the above address mapping, the first register of the TMS9918A will be at decimal address 52224.

The BASIC INTEGER of the Apple-1 handles numbers with the 16-bit Signed Integer format. This means that it can only handle integers between -32767 and 32767.
52224 is greater than 32767 (the largest acceptable number), so the numbering will the restart from -32767 and become a negative number.
To change a specific location using INTEGER BASIC, just use the negative value, for example:
POKE -13312.15
Of course, there are no "negative memory locations": it is just a matter of notation.

5. TECHNICAL NOTES ABOUT THE HARDWARE – POINTS OF ATTENTION

The board uses modern SRAM instead of the old and fragile DRAM originally used, together with some supporting ICs, necessary to realize this adaptation.

The starting project was the video part of the **LM80C computer** by Leonardo Miliani, already based on the work of J.B. Langston for the **RC2014 computer**, which was inspired most likely by the work of Tom LeMense (all references in the bibliography), with some modifications to the sequence of address lines.

The TMS9918A R/W line selection circuitry was inspired by an article in Byte magazine in August 1982 by Steve Ciarcia, with the addition of some logic gates for proper timing of the Write signal coming from the 6502 microprocessor.

The VDP is an asynchronous device and generates its own clock signal by using an internal oscillator and a quartz of a fixed value: **10.738635 MHz**. The allowed tolerance is +/-0.005%.
The NTSC color burst at 3.579545 MHz is derived from this oscillator and will carry the color information within the video signal.
So, if this value is not enough accurate, the monitor, *even if NTSC compatible*, will have difficulty to lock the color signal and, as a result*, the images will appear in black and white*.

Every crystal needs specific load capacitors, usually of some tens of pF: their values are declared in the product's datasheet.
The values in the schematic are therefore indicative and related to the crystal used on the prototype.
Capacitors should be chosen accordingly to the crystal used but should also consider the parasitic capacitances of the circuit and tracks.

To allow a small margin of adjustment, a small trimmer capacitor has been included on the PCB to allow a slight variation of the crystal oscillation frequency and therefore allow a satisfactory calibration.

The calibration should be done with a special insulating screwdriver (to avoid capacitive coupling during the calibration), and with extreme caution due to the extremely fragile nature of the compensator itself.
A check with a precision frequency meter is also recommended.

PLEASE NOTE: There is an IRQ/NMI jumper on the solder side to allow the computer to handle eventual interrupts generated by the TMS9918A.

It may be necessary to run some programs / demos / games.

Normally there should be a connection between the **center pin and the IRQ side**.

However, there may be incompatibilities when used simultaneously with some specific external devices, such as Wi-Fi Modem, or others that use interrupts. (https://p-l4b.github.io/wifi)

6. MANAGEMENT SOFTWARE

The TMS9918A is a complex device that has many internal registers, character maps, sprites, various resolutions etc. which can be complicated to program.

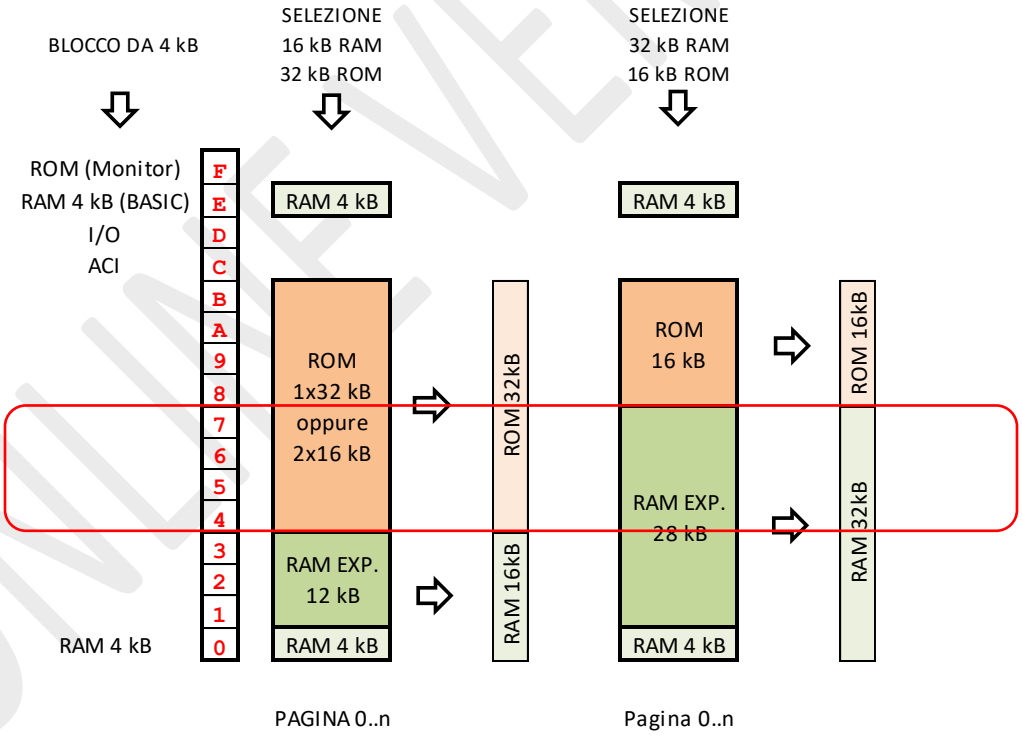
For this reason, it has been thought to reserve a wide range of memory to accommodate:

- software specifically written for it, such as test screens, simple demos, programs or games;
- repositories of routines in LM that perform simple and defined functions, recallable at will from other programs or BASIC, to help those who want to write their own programs.

The allocated memory range is: **$4000-$7FFF**, for a total of 16 kB.

The choice of this range has been motivated by the wish to make this board compatible and interoperable with the Juke-Box board (https://p-l4b.github.io/jukebox/).

This board can operate in this address range, exposing either RAM or ROM memory:



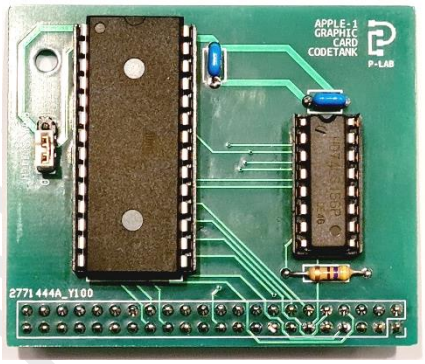
It is therefore possible to integrate Software/Routines etc. on to the Juke-Box ROM filesystem or load them on to the RAM. Software can be loaded also on CFFA1 ProDOS filesystem via CiderPress utility.

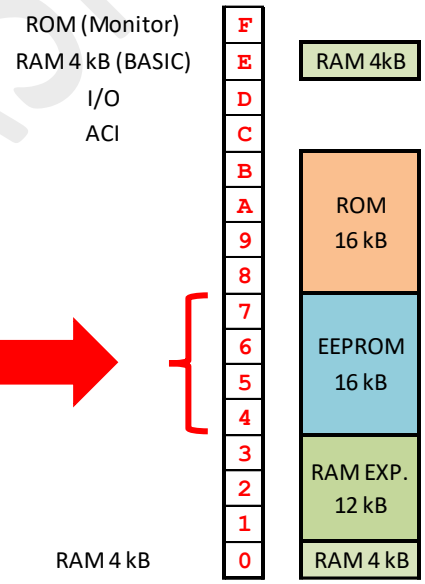
Also:
It is possible to set the Juke-Box to deallocate that address range **by removing the jumper 32K RAM-16K ROM / 16K RAM-32K ROM** as shown in the picture below.

This makes the connection of the "**CodeTank**" daughterboard possible, which will be therefore allocated in the dedicated memory area.

It is equipped with a 28c256 EEPROM and it is easily reprogrammable.
This EEPROM can contain up to 32 kB of routines and programs, divided in two 16 kB pages, independent and individually selectable through dedicated jumper.

The mapping provided here gives enough freedom and memory to the programmer to make complex projects and programs in both LM and BASIC (16 kB BASIC are fully available).





WARNING: Always remove the jumper before connecting the CodeTank card.

Please note that in this configuration the address space reserved for Juke-Box is 16 kB only. Therefore, if you want to use the programs on it (i.e. BASIC), an adequate ROM MAP jumper setting is required.
Also, Juke-Box's Flash memory needs to be programmed using the "16 kB" mapped files provided in the last ROM PACK.
However, some program might not work due to the overlapping memory mapping with the CodeTank.

5. BIBLIOGRAPHY - REFERENCES

Reference Manual of VDP TMS9918A:
http://www1.cs.columbia.edu/~sedwards/papers/TMS9918.pdf

Wiki of the TMS9918:
https://it.wikipedia.org/wiki/Texas_Instruments_TMS9918

Tom LeMense's SRAM on TMS9918A:
https://hackaday.io/project/160851-tms9918-vdp-with-sram-video-memory

J.B. Langston's TMS9918A Video Card for RC2014:
https://github.com/jblang/TMS9918A

Leonardo Miliani's LM80C:
https://www.leonardomiliani.com/lm80c/

Byte magazine #8 - 1982
https://archive.org/details/Hi-Res_Graphics_TMS9918_BYTE_0882

GitHub Repository for Software / Libraries:
https://github.com/nippur72/apple1-videocard-lib

We hope you enjoy using *Apple-1 Graphic Card!*

APPLE-1 GRAPHIC CARD

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