# Towards a Voltage-Controlled Computer Control and Interaction Beyond an Embedded System

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## ABSTRACT

The importance of embedded devices as new devices to the field of Voltage-Controlled Synthesizers is realized. Emphasis is directed towards understanding the importance of such devices in Voltage-Controlled Synthesizers. Introducing the Voltage-Controlled Computer as a new paradigm. Specifications for hardware interfacing and programming techniques are described based on real prototypes. Implementations and successful results are reported.

## Keywords

Voltage-controlled synthesizer, embedded systems, voltage-controlled computer, computer driven control voltage generation

## 1. INTRODUCTION

In this paper I intend to share my realizations in developing an extended embedded system for Voltage-Controlled Synthesizers (VCS)[6] - the ADDAC system - which is an instance of what could be called a Voltage-Controlled Computer (VCC). One of the main objectives is to provide a platform that allows an easy integration of computer driven operations in a VCS.

This project started in 2008 as a concept and has been under research and development since then motivated by the nonexistence of such a system. It underlines and stresses the idea of the Voltage-Controlled Synthesizer as a unique instrument with its specific characteristics, as described by Chadabe, *the voltage-controlled synthesizer is not a simple object. It is a hardware system that is different in many ways from computers and from many other devices or systems that are also referred to as synthesizers*[1].

## 2. BACKGROUND

*Analog synthesizers continue to be used by many musicians because of their distinctive timbres, intuitive real-time control and flexible patching*[2].

Beyond what would be expected, voltage-controlled synthesizers are stronger today than they ever were, this is reflected on the amount of brands on today's market[1][8][7]. This tendency overcomes predictions that after the 1980's such analogue devices would fell under the appearance of the digital synthesizers. In fact conversely to what was expected, nowadays we witness an inverted trend, as these (analogue) devices are only getting stonger. By the end of the 80's a few new companies started to emerge and new users were captivated to the analog world of modular synthesizers. This tendency seems to cross all musical forms, not being specific of any particular genre.

New manufacturer's, following the pioneer's tradition (Hugh Le Caine, Harry Olsen, Raymond Scott, Bob Moog or Don Buchla), are also musicians or enthusiasts with musical background and/or interests. They are the ones who are responsible for bringing a renewed popularity as well as new paradigms into the VCS field. One denotes easily that each of these brands' have a genuine and devoted interest in creating such systems, an interest that goes way beyond business revenues expectations.

### 2.1 "Hello World"

Throughout the last 20 years, but specially in the last ten, the use of digital components in analog synthesizers became more common and there's now a fair amount of digitally driven voltage-controlled modules that integrate microcontrollers or digital signal processors in its circuitry. Still, none of these offer any I/O communication protocol to an external digital platform, they are closed in their software and controlled only by their analog inputs and panel controls, e.g. knobs and switches.

## 3. THE PARADIGM SHIFT

The historical evolution focusing on the methods used for the integration of external digital devices (MIDI devices and personal computers) with the VCS.

### 3.1 Control Voltage

Control Voltage (CV) is the standard name adopted to refer to the voltage source signals that are used to operate a VCS. CV generation is made by specific synthesizer modules, e.g. LFO's, envelopes (ADSR's), sequencers and noise sources.

### 3.2 MIDI

Since the 80's different MIDI to CV modules have been developed to allow the new digital world to interact with analog systems. These modules were designed in order to open the possibility of connecting the new digital synthesizers

[1] http://wiki.muffwiggler.com/wiki/List_of_Modular_Synth_Equipment_Manufacturers


*NIME'11,* 30 May–1 June 2011, Oslo, Norway.

with MIDI output to the VCS, converting MIDI messages (Note and Velocity) to a relative constant voltage source. This voltage source could then be used to control different modules fuctions, for ex. to drive the frequency of a voltage-controlled oscillator (VCO) at quantized notes. These interfaces are still today's standards. Most of them are installed in the synthesizer cabinet, side by side with other modules, and powered from the VCS power supply.

The MIDI to CV and, later on, the CV to MIDI interfaces, act like a bridge (Figure 1) between any MIDI device and the VCS, this implementation also allows any computer to be connected through a standard MIDI interface and MIDI capable software. There's no processing done in these interfaces, their circuitry allows a linear conversion from a midi note to its relative constant voltage source at a standardized 1 volt per octave range. This analog to digital conversion uses 8 bit messages, where only 7 bits are used for note resolution, allowing a maximum range of 128 values. These interfaces are mostly monophonic, meaning that they only allows one note to be played at a time.

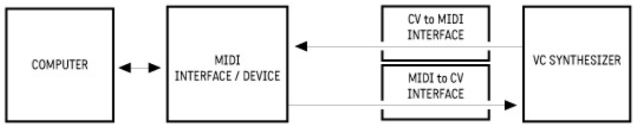


**Figure 1: MIDI Diagram, an integrated system**

## 3.3 VOLTA

In early 2009 MOTU released VOLTA, a virtual audio instrument, compatible with most audio software, that uses the outputs of an external sound card[2] to generate voltages. The voltages generated are defined by the track automation settings defined in the software. This only allow one way communication: from the computer into the VCS.

Likewise in MIDI communication, the sound card hardware acts like a bridge between the computer and the VCS, there's no processing done in the interface. The paradigm shift resides in the fact that the system does not intend to replicate the standard MIDI use, and not limit itself to solely translate notes to their relative frequencies, it goes beyond it. Using the sound card's, 16 bit resolution digital to analog converters, it allows a new range of possibilities, sweeps can now be effectively made and consequently the creation of LFO's, ADSR's, etc.

The aforementioned system requires that a computer node is present at all times, furthermore the necessary sound card is not integrated in the VCS cabinet which, besides affecting the ease of use, affects portability. Also regarding cabling, special cables are needed in order to connect both sides: mono jacks 1/4 inch to 1/8 inch.
(Figure 2)

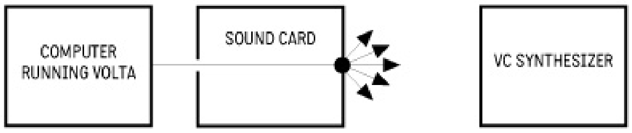


**Figure 2: VOLTA to CV Diagram, a non-integrated system**

[2]Not compatible with all soundcards, soundcard's outputs need to be DC coupled.

## 3.4 Conclusions

In my point of view, there's an underlining principle that can, in a first instance, effectively separate both approaches: integrated and non-integrated systems. Integrated systems like most MIDI to CV modules are installed in the VCS cabinet nad powered from its power supply. Non-integrated systems are peripheral devices not installed in the VCS cabinet and powered from their own power supply. This separation also highlights another distinction: the first approach is idealized from the synthesizer point of view, and the second from the computer point of view.

# 4. TOWARDS A VOLTAGE-CONTROLLED COMPUTER

By the end of 2009 I prototyped my first module (AD-DAC001 Brain Unit). The system was designed with very important features in mind:

1. For convenient usage, it was important that it was an **integrated system**, mounted in the synthesizer cabinet, side to side with all the other modules.
2. It would **not** be **computer dependent**.
3. If a computer is used, then the **communication would happen in two ways**, from the synthesizer to the computer and vice-versa.
4. Analog to digital and digital to analog **conversions** would have at least **16 bit resolution**.
5. It could be used in two ways:

   As a **"master" / standalone device**

   Or as **"slave device"** connected through one single usb cable straight to a computer

## 4.1 Definition

The Voltage-Controlled Computer (VCC) is an hardware based Embedded System locating itself in a specific spectrum of Embedded Computing (Figure 3) that also complies to the standards and tradition of the Voltage-Control Synthesizer as in [6][1][3].

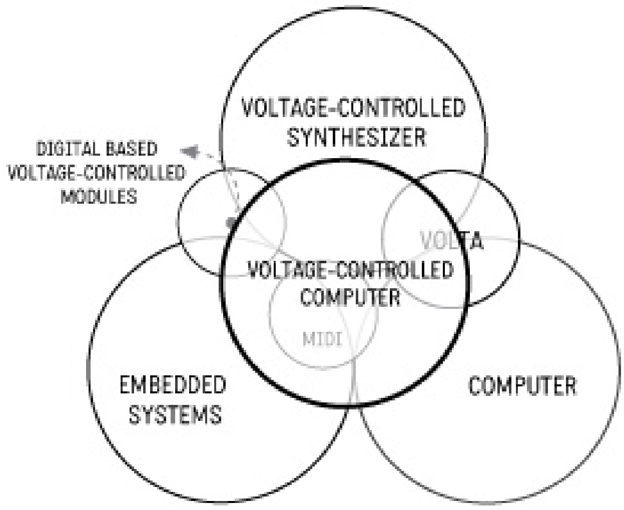


**Figure 3: Positioning diagram**

The VCC is not computer dependent.

The VCC creates a new paradigm in computer to VCS communication and interface. It no longer acts as a bridge between the digital world (computer or midi device) and the VCS, its microcontroller provide the autonomy and computational power to run complex algorithms that establish new interactions between analog and digital sources. (Figure 4)

Being a digital device, the VCC can be programmed to communicate to most digital platforms. These are regarded as peripherals that have specific functions that augment the possibilities and complexity of the system, e.g. a computer, MIDI device, mobile device, router, gamepad.

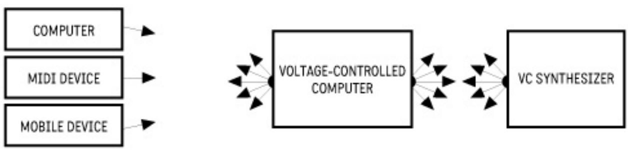


**Figure 4: VCC Diagram, an integrated system**

## 4.2 Standards

- The VCC complies with both Voltage-Controlled Synthesizer and Embedded Systems Design standards.
- The VCC analog inputs and outputs are converted to and from digital signal levels at standardized CV voltage sources. These Control Voltages operate at standardized VCS bipolar ranges.
- The VCC is comprised of one main module that hosts the microcontroller and optional expansion modules that expands both the system's possibilities and potential.
- The VCC connects to a standard VCS Bus Board and powers itself from standard bipolar power supplies.
- The VCC follows VCS standardized front panel dimensions.
- The VCC can communicate with the digital world through different standard communication protocols.
- The VCC trusts on its reentrant[5] software safety and reliability.


**Figure 5: ADDAC001Brain Unit Prototype I & II, 2010**

# 5. ADDAC SYSTEM

The VCC concept lead to the research and development of the ADDAC System[3]. This system has been developed in the last year and, due to public request, became a commercially available product.

## 5.1 Ground work

Most of the initial work was divided into two sections: the analog circuitry required to operate on bipolar voltages and the creation of dedicated software to run in the microcontroller.

The first Brain Unit prototype (Figure 5) resolved most of VCC's previously defined electronics specifications becoming a developer's platform for software programming and debugging.

## 5.2 The 00X System

The 00X System (Figure 6) is comprised of a Brain Unit and seven different expansion modules with specific functions that connect to the Brain Unit augmenting the interaction between the analog and digital worlds.

ADDAC00X System modules:

- ADDAC001 Brain Unit
- ADDAC002 CV / Manual inputs
- ADDAC003 Manual inputs
- ADDAC004 Gate inputs
- ADDAC005 Gate outputs
- ADDAC005W "Well tuned"[4]. gate outputs
- ADDAC006 Nunchuck input
- ADDAC007 Ethernet Input
- ADDAC008 Midi Input

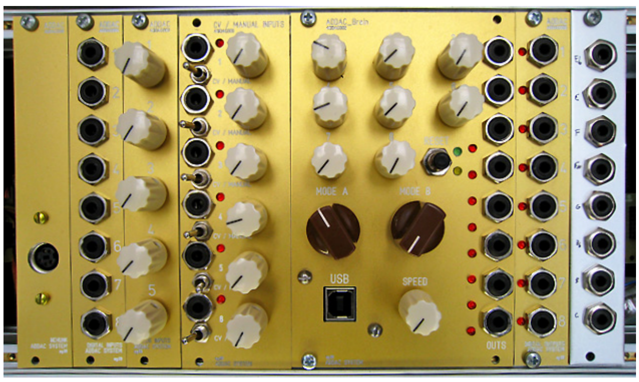


**Figure 6: The ADDAC System, March 2010**

## 5.3 Technical Specifications

The overall system architecture is developed around the Arduino[4] open-source hardware and software platform. The Arduino C++ code framework is stripped to its core developer's environment, the heart of the Brain Unit operating system is integrated in the Arduino software as an external library.

The adopted microcontroller is an ATMEL ATMEGA1280 running at 16 Mhz. The analog circuitry is designed to allow inputs and outputs at bipolar -10/+10 volts range (standard CV voltage range). Instead of using the microcontroller's

[3] `http://www.addacsystem.org`

[4] Arduino is an open-source physical computing platform based on a simple i/o board, and a development environment for writing Arduino software `http://www.arduino.cc`

dedicated analog and PWM pins, external, 16 bits resolution, Analog Devices converters (ADC's and DAC's) where also integrated in the schematic to maximize precision.

For USB communication an FTDI Serial to USB converter is used.

The system conforms to Eurorack[5] size format and use standard 3.5mm mono jacks for its physical inputs and outputs connections.

It also conforms to standard 8x2 pin Bus Board power connectors and -12 / +12 volts bipolar power supplies.

### 5.4 Front panel

ADDAC001 VS2. front panel features:

- 8 analog CV outputs
- 1 offset knob per output
- 1 led per output to monitor voltage state
- 2 Hex switch encoders to select pre-programmed presets
- 1 on-board knob to be assigned to any specific code function
- Reset Switch
- Midi input
- Nunchuck[6] remote input
- USB connector
- 2 led's to monitor Serial communication activity

### 5.5 Open-source C++ Framework

The C++ open-source framework defines most of the necessary setup for the software to operate properly, resolving most low level operations such as:

- Defining all specific pin I/O assignments, these are physical connections of the microcontroller's IC pins and were defined during the schematic development in order to have a clean pcb design.
- Facilitating classes to resolve most standard communication protocols, serial, MIDI, open sound control (OSC)[9].
- The integration of several algorithms like complex LFO's, linear and logarithmic ADSR's, Lissajous curves and complex randoms functions to mention just a few.

### 5.6 Software

There's four different possible ways for the system to communicate with a computer, these have different levels of technical know how required:

1. An open-source C++ library for advanced developers allows full access to the system's core software.
2. A set of open-source Max-Msp patches allows direct implementation, of pre-programmed classes, in Max-Msp
3. A standalone application with a dedicated GUI that integrates diferent protocols to interact, OSC, MIDI, Serial.
4. An Ableton Live audio instrument

## 6. CONCLUSIONS AND FUTURE DEVELOPMENTS

The system described brings new powerful tools to the use of the Voltage-Controlled Synthesizer, and follows its standards in voltage and operation method. It facilitates an integration with today's state of the art musical softwares, devices, controllers and programming frameworks be it through Serial, USB, OSC or MIDI. It provides a different and totally new method from the traditional MIDI to CV interfaces allowing new ideas to be developed due to its greater 16 bit precision range in converting digital to analog signals and vice-versa. It allows the user to rethink the computer interaction within an analog system facilitating new approaches, functions and integrations in an easy and user friendly way, not possible before with any commercially available module.

The system definitely fills a necessity I had in my analog modular system and has been the main control voltage source, putting aside most control voltage generators i had prior to this. It has also been used in most of my live performances proving to be one of the most important modules in my VCS. I've also been in close contact with the users who are already using it either discussing ideas and improvements, developing new functions or rethinking future hardware versions.

Future developments will mainly focus on two aspects that I find very important: Upgrading the CPU to a faster one, I realized that speed is the next issue that needs to be resolved, most probably to an ARM Cortex$^{TM}$ Processor[7], leave the Arduino environment aside and re-program the whole platform in C; Develop a dedicated software application for computers and mobile devices that, through a Graphic User's Interface, will allow users to program the microcontroller without needing to know any code language.

[5]Eurorack is one of today's most used VCS standard size format and follows the standard 19" Rack unit system measured in U's.

[6]Standard Nintendo Nunchuck Remote game controller.

[7]ARM Cortex$^{TM}$ is a popular processor used in devices like the iPad

## 7. ACKNOWLEDGEMENTS

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http://www.arduino.cc

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http://registeringdomainnamesismorefunthandoingrealwork.com

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