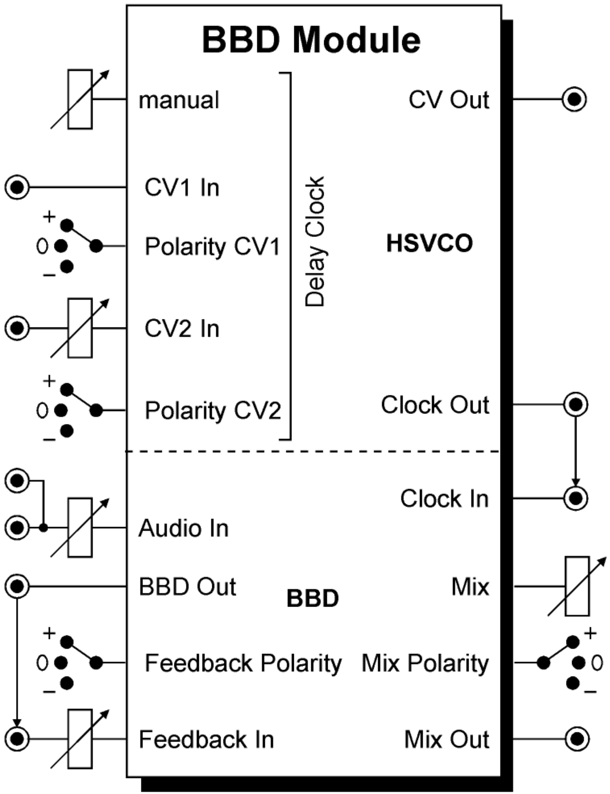


Fig. 1: A-188-1 Controls and In/Outputs

1. Introduction

Module A-188-1 is a so-called Bucket Brigade Device module (abbr. BBD). BBDs have been used to delay audio signals before digital delays dethroned the BBD based effect units. But BBDs have some very unique advantages (or disadvantages dependent on the point of view) over the digital counterpart which result from the special properties of the BBDs. BBD circuits can be treated as a chain of Sample&Hold units (S&H) which pass on their voltages to the next S&H in the chain at each clock pulse. A more detailed explanation – including the different types of BBDs – can be found in the following chapter.

In any case the sounds generated by module A-188-1 are very special. Typical applications are: Flanger, Chorus, Analog Delay or Karplus/Strong synthesis. But as the A-188-1 has a lot of very unique features (voltage controlled clock rate / delay time with extreme range, polarity switches for the CV inputs, feedback and BBD out/mix, clock and CV output of the high speed VCO, BBD clock input, feedback insert, feedback up to self-oscillation) a lot of unusual applications can be realized with the module (e.g. delay controlled by ADSR, random, envelope follower or sequencer with positive or negative effect). The A-188-1 also has no built-in anti-aliasing filter in order not to limit the possibilities of the module. For this the CV out is intended.

2. Basic Principles

As mentioned in the introduction a BBD circuit can be regarded as a chain of Sample&Hold units (S&H) which pass on their voltages to the next S&H in the chain at each clock pulse. From this also the name Bucket Brigade Device is derived as each stage of the BBD can be treated as a bucket. At each clock pulse the content of each bucket is forwarded to the next bucket in the chain and the current bucket is filled with the contents of the preceeding bucket.

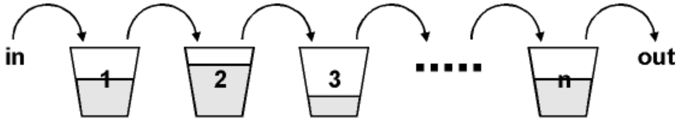


Fig.2: Bucket Brigade

Remark: In reality two "buckets" are required for each stage as the content of a bucket has to be stored temporarily in a "slave bucket" before it can be filled with the contents of the preceeding bucket, in contrast to a "real" bucket brigade not the buckets are passed on but only the contents.
In the BBD the water is replaced by analog voltages which again represent audio signals. The first bucket (1) is the audio input, the last bucket (n) is the output of the BBD. As in reality there are losses while the water (resp. voltage) is passed on, because some drops of water go wrong and at the end of the chain not the same amount of water (resp. not exactly the same voltage) appears. In a BBD the buckets are replaced by capacitors and analog switches. As the capacitors of a BBD are very small (some pF only) even the time required to pass on the input to the output is crucial as the capacitors loose their charges if it takes too long. This is why a minimum clock frequency is specified for each BBC circuit. Below this frequency the flawless operation of a BBD is not guaranteed. In the A-188-1 intentionally frequencies can be used that go below this value to obtain special "dirty" and "crunchy" effects.
BBD circuits are available (or rather have been available) with different number of stages. Usual numbers are 128, 256, 512, 1024, 2048 or 4096 stages. Currently (as of spring 2006) only devices with 1024 and 2048 are still in production. Other BBDs are obsolete, hard to find and very expensive. Therefore only the versions of the A-188-1 with 1024 and 2048 stages are standard products. All other versions of the A-188-1 are available only while stocks of the corresponding BBD circuits last.
The number of stages defines the delay time that corresponds to a certain clock frequency. The higher the number of stages, the longer is the delay. The higher the clock frequency, the shorter is the delay.

Example: At 100kHz clock frequency the delay time is 10.24 ms for a BBD with 1024 stages and 20.48 ms for a BBD with 2048 stages.

The following table shows the relation between clock frequency, delay time and number of stages for some typical BBD circuits.

Relation between clock frequency [kHz] and delay time [ms]							
		BBD circuit number of stages					
clock frequency (clock input socket)	BBD clock frequency (= 1/2 clock input)	MN3006 MN3206	MN3009 MN3209	MN3004 (*) MN3204	MN3007 (*) MN/BL3207	MN3008 MN/BL3208	MN3005 MN3205
[kHz]	[kHz]	128	256	512	**1024**	**2048**	4096
1	*0,5*	*128,00*	*256,00*	*512,00*	***1024,00***	***2048,00***	*4096,00*
2	*1*	*64,00*	*128,00*	*256,00*	***512,00***	***1024,00***	*2048,00*
5	*2,5*	*25,60*	*51,20*	*102,40*	***204,80***	***409,60***	*819,20*
10	*5*	*12,80*	*25,60*	*51,20*	***102,40***	***204,80***	*409,60*
20	10	6,40	12,80	25,60	**51,20**	**102,40**	204,80
50	25	2,56	5,12	10,24	**20,48**	**40,96**	81,92
100	50	1,28	2,56	5,12	**10,24**	**20,48**	40,96
200	100	0,64	1,28	2,56	**5,12**	**10,24**	20,48
300	150	0,43	0,85	1,71 (*)	**3,41 (*)**	***6,83***	*13,65*
400	200	0,32	0,64	1,28 (*)	**2,56 (*)**	***5,12***	*10,24*
500	*250*	*0,26*	*0,51*	*1,02*	***2,05***	***4,10***	*8,19*

(*) The max. clock frequency is 100 kHz only for MN3004 and MN3007 (in contrast to 200kHz for MN3204 and MN3207)

Remarks:

The standard versions of the A-188-1 with 1024 and 2048 stages are marked with **bold** characters.

The *grey italic* characters indicate parameters out of the data sheet specifications (e.g. clock frequencies below 10kHz for all BBD devices, and clock frequencies beyond 100kHz or 200kHz for certain BBD devices). But parameters out of spec may be available with the A-188-1. As the BBD devices cannot be damaged if they are operated with frequencies out of spec we decided to allow such frequencies with the A-188-1 to obtain special audio effects – especially for clock frequencies below 10kHz. But the regular behaviour is no longer guaranteed (especially increasing voltage losses at lower frequencies). As the clock frequency falls below ~ 20 khz the clock signal itself will become audible. This clock noise can be used as unusual audio source or it can be filtered out with an external low pass filter.

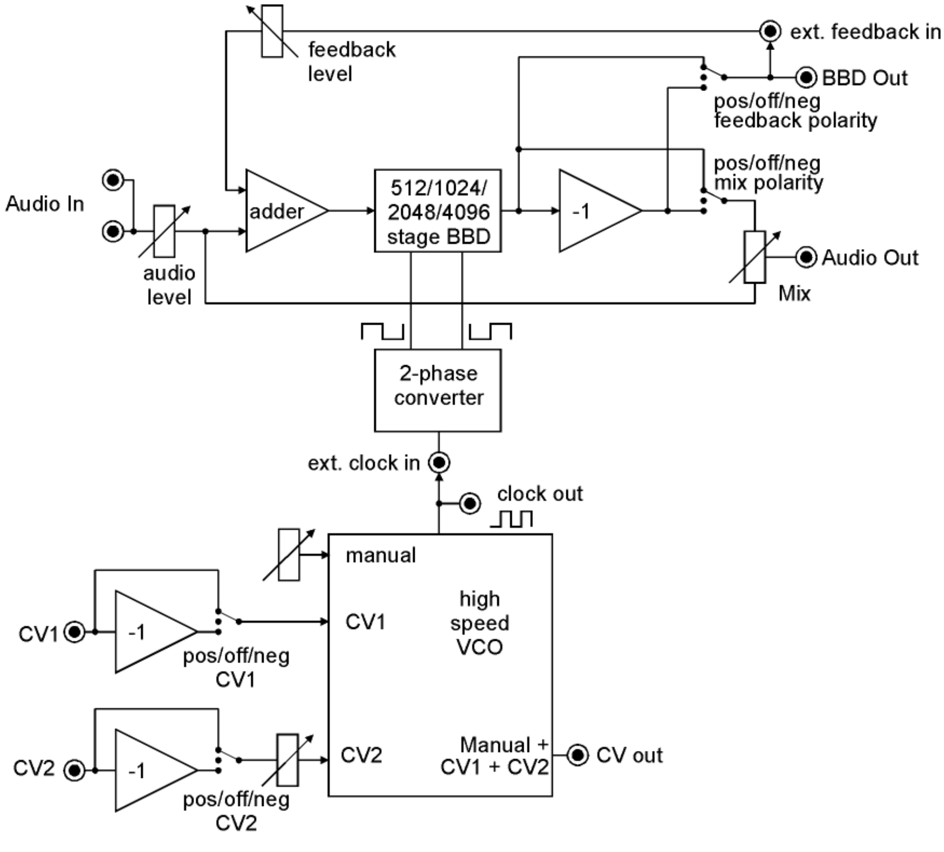


Fig. 3: A-188-1 module scheme

Fig. 3 shows the internal details of the module A-188-1: the upper part is the actual BBD section, the lower part the high speed VCO (HSVCO).

The HSVCO generates the clock signal that is required to drive the BBD. It has available a manual control and two CV inputs (CV1 without attenuator, CV2 with attenuator). For both CV inputs three-position polarity switches (negative / off / positive) are available. The position of these switches defines if a positive going CV has positive, none or negative effect on the clock frequency. CV1 has a sensitivity of approximately 1V/octave. The HSVCO has a CV out available that corresponds to the sum of all CVs (manual, CV1 and CV2). It's main purpose is to control the CV input of one or two external low pass filters that can be used as anti-aliasing filter and clock filter. If desired one low pass filter can be used behind the audio output to suppress the clock noise when the clock frequency falls below ~20 khz. Another filter can be used at the audio input to reduce the max. frequency of the incoming audio signal, consequently reducing aliasing artefacts. As the CV output reflects the clock frequency (affected by the manual control, CV1 and CV2) the external filters automatically follow the clock frequency of the BBD module. The higher the slope of the external filter (e.g. 12/24/48 dB/octave) the better is the clock suppression. The HSVCO features a clock output that can be used e.g. to synchronize two A-188-1 (i.e. both A-188-1 use the same clock source) or as high speed clock for other applications (e.g. graphic VCO, switched capacitor filter).

The clock output of the HSVCO is normalled to the clock input of the BBD section. The clock input makes it possible to control the BBD by an external clock source (e.g. another A-188-1 or any other clock signal in the required frequency range). For all clock signals from and to the A-188-1 only short patch cables should be used, as long cables function as low pass filters for signals above 20kHz.

A two-phase converter generates the two opposite clock signals that are required to drive the BBD circuits.

The audio input of the BBD module is equipped with an attenuator that enables to reduce the input level to avoid distortion. The audio input signal behind the attenuator is mixed with the feedback signal (details below) and fed to the audio input of the BBD circuit. The audio output of the BBD is processed by an inverter to have both the normal and the inverted BBD output available. The reason for this feature is that the polarity is crucial for both the output mixing (BBD + original) and the feedback behaviour of the module. The normal output of the BBD and the inverted output are fed to the terminals of two three-position polarity switches (negative / off / positive) for mixing polarity and feedback polarity.

The output mixer is used to mix the original signal with the normal or inverted BBD signal. The position of the mix polarity switch defines if the normal, none or the inverted BBD output is mixed with the original audio signal.

The following sketch shows the effect of normal/inverted mixing by means of a simple sawtooth signal as audio input.

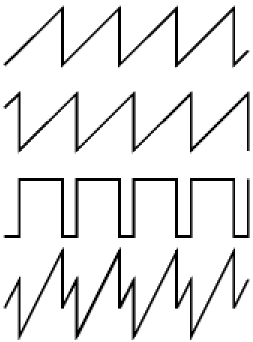


Fig. 4: positive/negative mixing of original and BBD signal

The center terminal of the feedback polarity switch is connected to the BBD output socket. Pay attention that the polarity of this output is affected by the position of the feedback polarity switch (especially there is no signal at the output socket if the switch is in the center position) ! The feedback input is normalled to the output socket. The combination of these two sockets allows to process the feedback loop with external modules (e.g. a VCA or a VC polarizer for voltage controlled feedback, or other modules like filter, phaser, frequency shifter, waveshaper, wave multiplier, ring modulator or another BBD module for special voltage controlled feedback effects)

The polarity of the feedback signal leads to clearly audible different sounds as different frequencies are emphasized or attenuated for positive or negative feedback.
The feedback can be increased up to self-oscillation. In contrast to other feedbacks (e.g. filters, phasers) the result in the self-oscillation state depends upon the "audio history" (i.e. the contents of the BBD when the self-oscillation is triggered). The reason is that there is not only one possible stable self-resonant state for the BBD. Any cyclic waveform "stored" in the BBD is able to resonate provided that the feedback maintains the waveform. One can try this out e.g. with different audio signals (e.g. digital noise and VCO sawtooth) as audio input before self-oscillation is triggered (e.g. by switching the feedback polarity switch from center position to positive or negative position).

Different BBD circuits (128/256/512 ... 4096 stages) influence a lot of sound parameters. Of course the delay time range and consequently the basic sound, but even the feedback behaviour (both the self-oscillation and the "smoothness" of the feedback), the distortion behaviour and the output level. It is hard to say which is the "best" solution. It depends upon the desired sound "bending". For typical analog delay sound BBDs with more stages are the better solution. But for "oppressive" flanging sounds caused by short delays or for Karplus-Strong synthesis shorter BBDs are recommended.

3. Overview

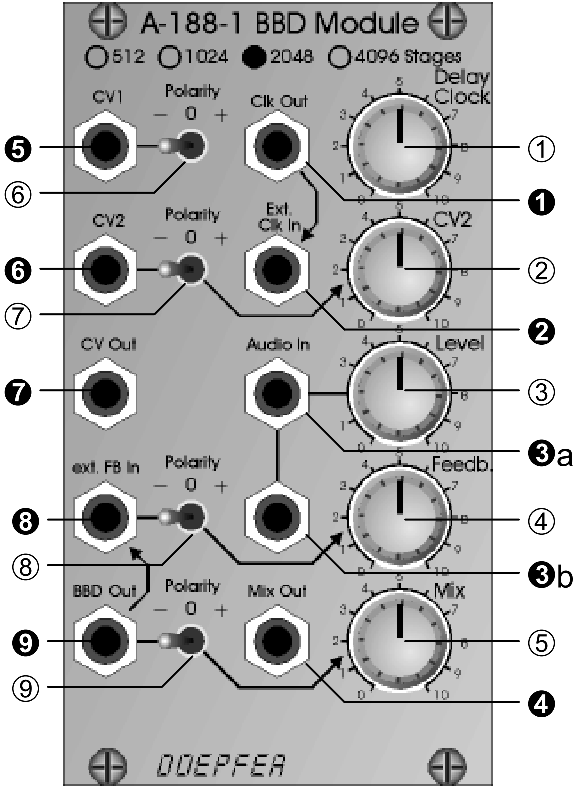


Fig.5: A-188-1 front panel

Controls:

① Delay Clock : manual delay control
② CV2: attenuator for CV2
③ Level: audio input attenuator
④ Feedback: feedback level control
⑤ Mix: mix control (original/BBD)
⑥ Polarity: CV1 polarity
⑦ Polarity: CV2 polarity
⑧ Polarity: feedback/BBD Out polarity
⑨ Polarity: mix polarity

In- / Outputs:

❶ Clk Out: clock output HSVCO
❷ Ext. Clk In: BBD clock input (normalled to Clock Out ❶)
❸a Audio In: audio input (connected to ❸b)
❸b Audio In: audio input (connected to ❸a)
❹ Mix Out: mixed output
❺ CV1: CV1 input HSVCO
❻ CV2: CV2 input HSVCO
❼ CV Out: CV output HSVCO
❽ Ext.FB In: external feedback input (normalled to BBD Out ❾)
❾ BBD Out: BBD output (affected by polarity switch ⑧)

Attention: the front panel markings are wrong concerning the BBD Output and the feedback polarity switch. Please refer to the scheme on page 4.

4. Controls and In- / Outputs

4.1. High Speed VCO Section

① Delay Clock : manual delay control
❺ CV1: CV1 input HSVCO
⑥ Polarity: CV1 polarity
❻ CV2: CV2 input HSVCO
⑦ Polarity: CV2 polarity
② CV: attenuator for CV2

This group of elements is responsible for the clock frequency generated by the high speed VCO (HSVCO). knob ① *Delay Clock* is used to adjust the clock manually. Two CV inputs (❺ CV1, ❻ CV2) are available to control the clock by external control voltages (e.g. LFO, envelope follower, random, ADSR, keyboard CV, sequencer, theremin, ribbon controller, foot controller, Midi-to-CV, shepard generator ...). The sensitivity of CV1 is approximately +/– 1V/oct according to the position of the CV1 polarity switch ⑥. The diagram on the right side shows the connection between CV1 and clock frequency. The straight line represents the perfect 1V/oct graph. The slightly bended curve is the real behaviour of the HSVCO. If an absolutely "perfect" 1V/oct control is required an external precision HSVCO or a VCO with PLL has to be used.

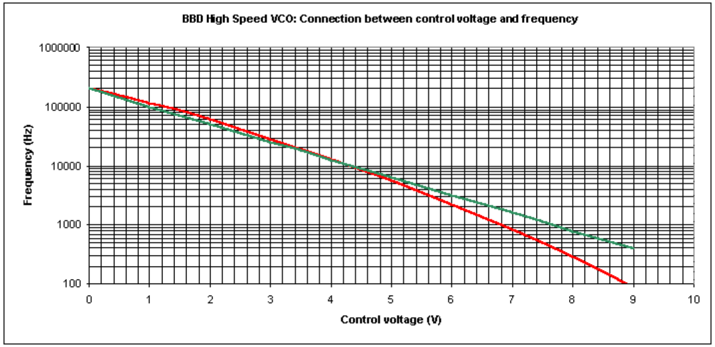


Fig 6: relation between CV1 and Clock Frequency

Both CV inputs are equipped with polarity switches (⑥, ⑦). According to the position of these switches the effect of the corresponding CV is positive (i.e. increasing CV increases the clock frequency), off, or negative (i.e. increasing CV decreases the clock frequency).

❶ Clk Out: clock output HSVCO

This is the clock output of the HSVCO. It is internally connected to the clock input of the BBD section. The waveform is rectangle with about ± 3V level. The rectangle slopes flatten with increasing frequency and the waveform turns more and more into triangle. Even the load on the output has influence to the waveform and level.

Consequently for all clock patches from and to the A-188-1 only short patch cables (~ 30 cm) should be used as long cables function as low pass filters for signals above 20kHz. The max. frequency at this output depends upon the BBD used in the module and is related to the max. clock frequency of the BBD in question (pls. refer to the table on page 3). It is about 250 kHz for BBDs with 2048 and 4096 stages and about 450kHz for BBDs with 1024 stages and less (i.e. a bit more than the max. clock frequency of the specs in the data sheet). If the BBD circuit is changed the max. frequency has to be re-adjusted with a trimming potentiometer on the pc board of the module (frequency offset). For details please refer to the appendix of this manual.

❼ CV Out: CV output HSVCO

This CV output indicates the clock frequency at output ❶ and is nothing but the sum of all CV inputs (manual, CV1 and CV2). The main purpose of this output is to control the CV input of one or two external low pass filters that can be used as anti-aliasing filter and clock filter. If desired one low pass filter can be used behind the audio output to suppress the clock noise when the clock frequency falls below ~20 khz. Another filter can be used at the audio input to reduce the max. frequency of the incoming audio signal, consequently reducing aliasing artefacts. As the CV output reflects the clock frequency (affected by the manual control, CV1 and CV2) the external filters automatically follow the clock frequency of the BBD module. The higher the slope of the external filter (e.g. 12/24/48 dB/octave) the better is the clock suppression. But the CV output can be used for other applications as well, e.g. controlling parameters of the feedback loop like feedback amount/polarity (CV of a VCA or VC polarizer used in the feedback loop), filter frequency (CV of a VCF used in the feedback loop), phase shift (CV of a VC phaser used in the feedback loop).

4.2. BBD Section

❷ Ext. Clk In: BBD clock input

This is the clock input of the BBD section and is internally connected to the clock output ❶ of the HSVCO section (i.e. it is normalled to the Clock Out socket ❶). If an external clock source is used the clock output of this source is patched to socket ❷. In this case the internal connection to the HSVCO is interrupted. The suitable clock frequencies depend upon the BBD used in the module (pls. refer to the table on page 3). The required level for the clock signal is 0/+5V (levels up to +12V cause no problems). This socket can be used e.g. to synchronize two A-188-1 modules (i.e. using one HSVCO for both modules).

❸a/b Audio In: audio input
③ Level: audio input attenuator

Sockets ❸a and ❸b are the audio input with the assigned attenuator ③. The two sockets are internally connected (miniature multiple). The second socket can be used to forward the audio input signal to other modules (e.g. to a VCA or VC polarizer or VC mixer for voltage controlled mixing functions). Feed the audio signal that has to be processed with the BBD effect into socket ❸a or ❸b. Adjust the *Level* control ③ so that the output signal does not distort - unless you want to obtain distortion. For normal A-100 levels (e.g. VCO A-110) distortion appears at about three o'clock position of control ③ but the distortion behaviour depends also upon the BBD circuit used in the module.

❾ BBD Out: BBD output

Socket ❾ is the "raw" BBD output (i.e. not mixed, not filtered). Pay attention that it is affected by polarity switch ⑧).

<u>Remark:</u> The front panel markings of the first two productions series are wrong concerning the BBD Output and the feedback polarity switch. Please refer to the scheme on page 4.

The BBD output can be used e.g. for voltage controlled mixing functions (i.e. if the original signal and the BBD signal are mixed externally with VCAs or VC polarizers or a VC mixer).

❹ Mix Out: mixed output
⑤ Mix: mix control (original/BBD)
⑨ Polarity: mix polarity

This group of elements is responsible for the mixed output appearing at socket ❹ *Mix Out*. In the left/ccw position of knob ⑤ *Mix* the original signal appears at socket ❹. In the right/cw position of knob ⑤ the pure BBD signal appears at socket ❹. In the intermediate positions of knob ⑤ a mix of these two signals appear at the output socket. For a standard flanger effect e.g. the center position is used.

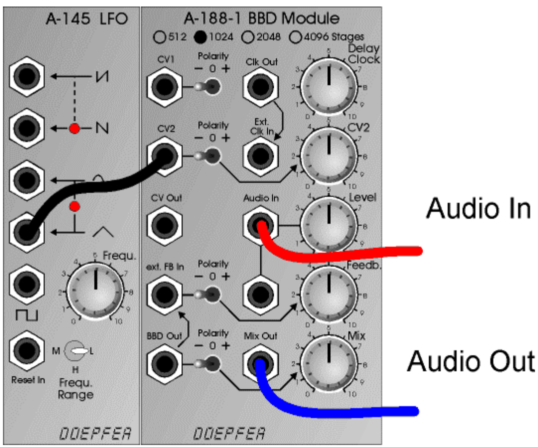
The position of the polarity switch ⑨ defines if the normal or the inverted BBD signal is mixed to the original signal (please refer to page 6 concerning this function). Especially for short delay times the position of this switch leads to clearly audible different sounds. In the middle position of the switch the BBD share of the mixed signal is off and only the original signal is heard. Consequently the switch can be used to turn on/off the BBD effect at the mix output ❹.

❽ Ext.FB In: external feedback input
④ Feedback: feedback level control
⑧ Polarity: feedback/BBD Out polarity

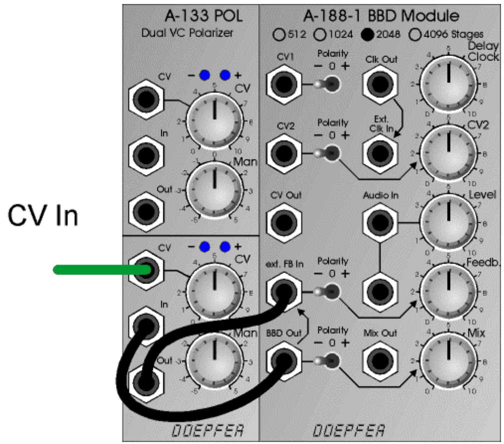
This group of elements is responsible for the feedback functions of the module. Socket ❽ *Ext.FB In* is the input of the feedback loop and is normalled to socket ❾ *BBD Out*. If an external module is used to control the feedback loop (e.g. a VCA or VC polarizer) the module has to be inserted between socket ❾ *BBD Out* and socket ❽ *Ext.FB In*. The polarity switch ⑧ controls the polarity of the signal appearing at the socket ❾ *BBD Out* and consequently the polarity of the feedback signal. In the center position of switch ⑧ the signal at socket ❾ *BBD Out* is off and no feedback is active. Consequently the switch can be used to turn on/off the feedback effect. The polarity of the feedback signal leads to clearly audible different sounds at short delay times. For longer delay times ("analog delay" application) the sound differences are much smaller (for details please refer to page 6).

Knob ④ *Feedback* adjusts the feedback level. In the left/ccw position of the knob no feedback (or resonance/emphasis) is added. As the knob is turned right/clockwise feedback occurs. In the fully right/cw position the module goes into self-oscillation. As already mentioned in chapter 2 the result in the self-oscillation state depends upon the "audio history" (for details please refer to page 6). Both the self-oscillation behaviour and the "smoothness" of the feedback also depend upon the BBD circuit used in the module (128/256 ... 4096 stages).

5. User Examples



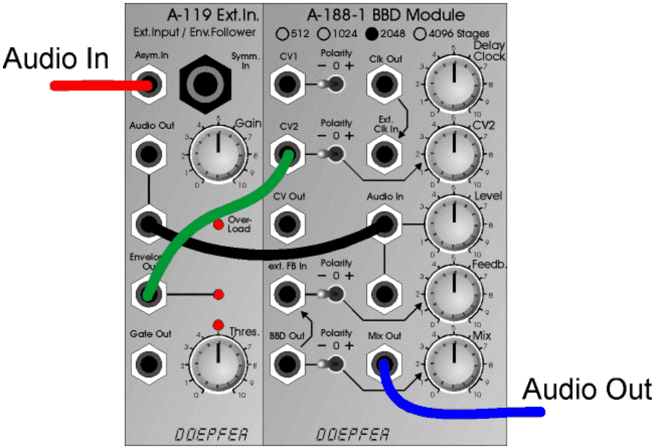
Standard Flanger Patch



Voltage Controlled Feedback

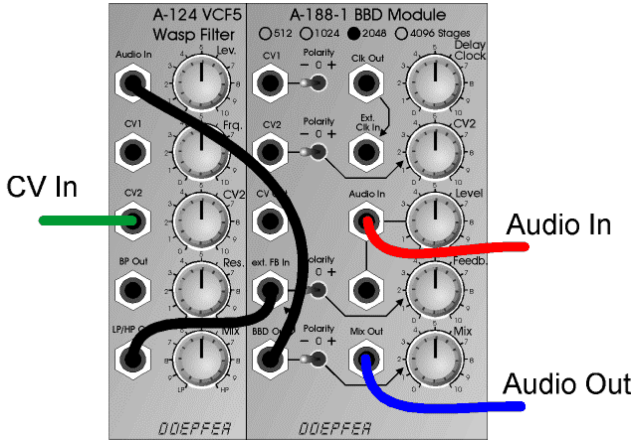
Suitable control voltage sources are LFO (A-145 as shown in the example, A-146, A-147, A-143-3), random voltage (A-118, A-149-1), envelope (A-140, A-141, A-142, A-143-1, A-143-2), S&H (A-148, A-152), sequencer (A-155), theremin (A-178), ribbon controller (A-198).

Feedback is processed by an external voltage controlled polarizer (A-133) to obtain voltage controlled feedback. Instead of the polarizer even a VCA can be used. But with a VCA only positive or negative feedback is possible.



"Enveloped" BBD

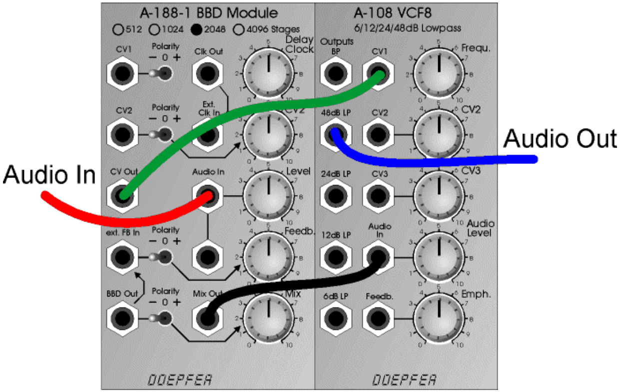
Control voltage for the A-188-1 is generated by the envelope of the processed audio signal. Try positive and negative setting of the CV2 polarity switch and different CV2 levels !



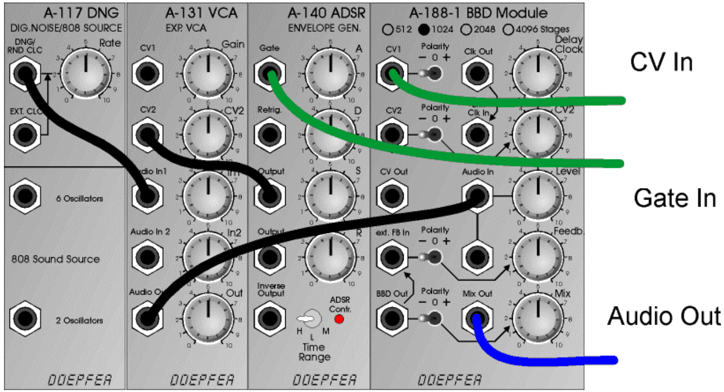
Filtered Feedback

The feedback loop is processed by an external filter. The example shows an A-124 Wasp filter in the feedback loop. But any low pass, high pass, band pass or notch filter (even multiple filters like A-104 or A-127), phasers (A-101-3, A-125) or frequency shifter (A-126) can be used.

Especially for the Karplus/Strong Synthesis (see below) a low pass filter is useful in the feedback loop to simulate the natural behaviour of a plugged string by damping higher frequencies in the decay phase.



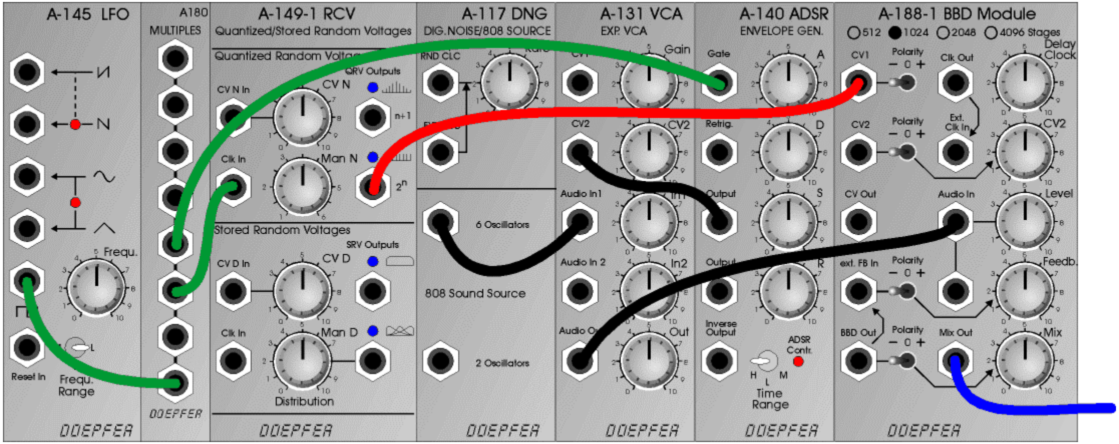
Clock Filter



Basic Karplus/Strong Synthesis Patch

The BBD audio output is filtered with a low pass (e.g. A-108). The frequency of the low pass filter follows the BBD clock frequency as the CV output of the module A-188-1 is used to control the frequency of the low pass filter. A second filter can be used at the audio input of the A-188-1 to limit the frequency range of the processed audio input signal.

CV and gate are delivered e.g. by a sequencer, ribbon controller, Midi-to-CV interface or Theremin. The time parameters of the envelope generator (ADSR A-140) and the feedback settings of the A-188-1 define the sound – especially the decay time. If voltage controlled envelope generator (e.g. A-141) and a VCA or VC polarizer are used to process the feedback loop all parameters are voltage controlled. Even other sound sources (6 oscillators or 2 oscillators of the A-117, noise signal of an A-118, or VCO, or only short "click" of the ADSR) can be used. For more realistic Karplus/Strong applications a filter in the feedback loop can be used (see previous page).



Karplus/Strong Random melody patch (A149/1)

This patch shows another example for the Karplus/Strong synthesis. The LFO A-145 is used as clock oscillator but any other clock source could be used as well. The rectangle output is connected to the clock input of the Quantized / Stored Random Voltages module A-149-1 (upper or lower section may be used) and to the gate input of the envelope generator A-140. One of the quantized or stored CV outputs of the A-149-1 is patched to the CV1 input of the A-188-1. The rest of the patch is the same as the basic Karplus/Strong Synthesis Patch (only the "6 oscillators" output of the A-117 is used instead of the digital noise output in the basic patch).

The patch generates a random melody. The tempo is defined by the LFO rate, the tone range by the "N" settings of the A-149-1 (Manual "N" and possibly CV "N"). Additional modules can be used e.g. to modulate "N" of the A-149-1 or the decay time of a voltage controlled envelope generator (e.g. A-141 or A-142 instead of the A-140) by another random voltage of the A-149-1.