Guitar Innovation: Polyphonic Distortion with Multichannel Guitar Pickups

A White Paper about the technology behind Spicetone's 6APPEAL™ hexaphonic sound processor and its applications
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1 Hexaphonic and Multichannel Pickups

First of all, let us clear some confusion in vocabulary. A guitar pickup is a device that *captures mechanical vibrations from stringed instruments such as the electric guitar[1].* The gear we are discussing, uses a special kind of pickups that can capture a separate signal for each string. These pickups are referred to as divided, MIDI, synth, synth access, V-Guitar, hex, hexaphonic, multichannel or polyphonic pickups.

Strictly speaking, the word *hexaphony* only refers to a six string / six channel gear and processing. There are guitars with seven, eight or more strings, so it would be more correct to use words *multichannel* and *polyphonic*. On the other hand, most guitars and multichannel pickups are still for six string instruments, so we will mostly stick to the widely used words *hexaphonic*, *hexaphony*, and *hex*.

For hexaphonic processing one needs hexaphonic pickups. As said, these are also called divided pickups. Hexaphonic effects are processing the signals from each string separately, thus giving a distinctive sound compared to monophonic effects.

LEFT: A Roland GK-3 in custom middle position.   RIGHT: A Godin acoustic guitar with common 1/4" and multichannel 13pin output.

Examples of guitars with hexaphonic pickups are Fender GK-Ready Stratocaster and many so called Synth Access (SA) models from Godin. You may also fit your guitar with Roland GK-3 Divided Pickup or respective GK-3B pickup for bass guitars. These guitars are connected to hexaphonic processors over (Roland standard) 13pin connector/cable. Other examples are Graph Tech Ghost, Cycfi Neo6 pickups, Ubertar pickups, Carvin MIDI synth access custom guitars. *The earliest pickup /.../ with anything similar to hexaphonic construction was on a Regal guitar from circa 1935–36[2].*

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[1] http://en.wikipedia.org/wiki/Pickup_%28music_technology%29
[2] http://www.premierguitar.com/articles/Putting_the_Hex_On_the_Postmodern_Pickups

2   Tangled up in Atonalities

Distortion effects create "warm" and "dirty" sounds by compressing the peaks of an electric musical instrument's sound wave, which results in a large number of added overtones[3].

One of the most obvious applications for a multichannel pickup is to use it for hexaphonic distortion. A hexaphonic distortion processor produces dramatically different sound compared to traditional monophonic distortion modules, especially when the guitar is played polyphonically (two or more strings sounding the same time). Hexaphonic distortion is harmonically much richer, with orchestral or choir like qualities. This is also referred to as polyfuzz.

Playing an electric guitar with traditional monophonic pickups, there is a clear difference in sound when playing instrument monophonically (single string at the time) or polyphonically (several strings at the same time).

When monophonic sound is distorted (overdriven), the resulting sound gets richer because of all the added harmonics. These are tonally related to the original sound. But with a monophonic pickup, all signals (notes) are picked up together. Hence, the bunch of signals is distorted together, too.

If distorting summed guitar signals in a single channel, as is the case with conventional distortion effect pedals for guitar, in addition to harmonically related content, many new frequencies are generated. One could expect, these extra frequencies result in richer harmonics, but on the contrary – the sound gets spoilt by atonalities.

To dig a bit deeper, the summed distortion of several string signals creates harmonics, which are related to every possible sum or subtract of frequencies from the original sound, including frequencies between the harmonics of the original sound and generated harmonics. These, so called intermodulation frequencies, are atonal and not harmonically related to the sound origin. This creates a sound that is described as musically muddy sound, trashy or harsh. It still may deserve for your artistic purpose. Some intervals, so called power chords[4], have much less trouble with atonal components, so this is why distorted guitar players mostly resort to using the power chords or just a couple of strings simultaneously.

About technical background of intermodulation distortion, which is also related to conventional monophonic distortion effects, we recommend the user to check out a very good [Wikipedia article](http://en.wikipedia.org/wiki/Intermodulation)[5] about the issue.

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[3] http://en.wikipedia.org/wiki/Distortion_%28music%29
[4] http://en.wikipedia.org/wiki/Power_chord
[5] http://en.wikipedia.org/wiki/Intermodulation

3   Polyphonic / Hexaphonic Distortion

In a **hexaphonic distortion** device the signals from **each of the six strings are distorted separately**. This creates **only tonal components** in respect to the original signal. Mixing these signals linearly after the distortion processing does not create any atonal components, as long as the processing stays linear. Thus the hexaphonic distortion sounds very tonal, and has some obvious orchestral character.

We compared two spectrograms of a chord played through EHX Big Muff Pi and 6Appeal, respectively (see the illustration below). Please draw your attention to the spectral difference in the outlined frequency range from 500Hz to 1kHz. There is much more "life" in the Big Muff Pi spectrum due to the excessive amount of intermodulation between the root frequencies of the string signals. 6Appeal spectrum in this range is more "clean"; closer analysis reveals that the dominating spectrum peaks are harmonically related to the root frequencies of each string played.
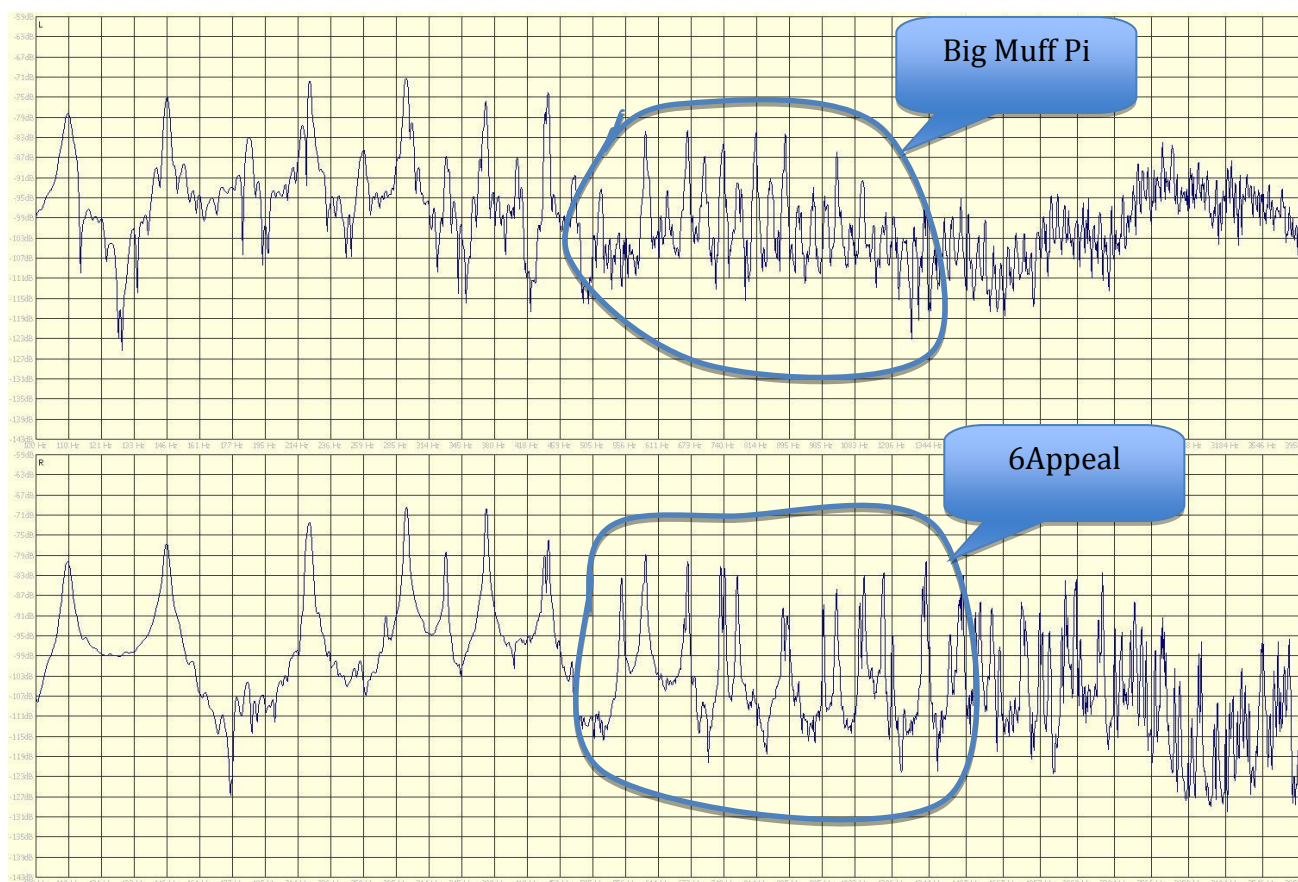
A chord played through EHX Big Muff Pi and 6Appeal.

The spectrum sample is taken with Wavelab 7 from sound of Spicetone Youtube video "Big Muff vs 6appeal[6]". It is the third accord (the long sounding one) of the first sound example, for both Big Muff Pi and 6Appeal, respectively.

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[6] https://www.youtube.com/watch?v=nw-RMAnBccg

Without claiming that the hexaphonic distortion is better than traditional distorted sound, it clearly is very much different, and opens up new artistic possibilities like playing a distorted guitar with open chords or using hexaphonic overdrive when playing guitar in finger style. "If only Bob Dylan had one of these when he went electric," said Mr Nigel Cassidy from BBC news, when he visited Spicetone's laboratory.

4   Applications of Polyphonic Distortion Pedals

As for the moment (December 2014), the only known distortion device with analog multichannel sound processing that is in serial production, is 6Appeal pedal by Spicetone. Besides this, there are several devices by Roland Corporation that apply digital processing or sampling to accomplish sounds, similar to hexaphonic distortion (polyfuzz) - these are Roland V-Guitar solutions[7] GR-D, GR-55, VG-99, and Boss GP-10. Besides that, one can use a converter like Terratec Axon AX100 to control any MIDI synth with a hex guitar (13pin output).

Furthermore, there are devices called breakout boxes. These are meant for routing separate signals from a multichannel pickup to other devices or to the computer environment (DAW, digital audio workstation) for further processing. Breakout boxes open very interesting possibilities for multi-channel granular synthesis and spatialization (read more[8] and even more[9]).

Besides being a multichannel overdrive box for polyphonic distortion, Spicetone's 6Appeal doubles as a breakout box. Both clean or overdriven sounds can routed from 6Appeal to a soundcard (1/4" outputs) or other 13pin devices (through 13pin output). As 6Appeal can be controlled with MIDI in every aspect, this makes it possible to set up a sophisticated system, centered on a guitar. Output to a surround array of speakers, synchronization with lightning effects or live video – applications are inexhaustible.

One thing to keep in mind, when setting up your hexaphonic system, is that current hexaphonic pickups are not ideal. They do pick up faint signals from neighboring strings, delivered either by a magnetic field or through the guitar body, the latter in the case of multichannel piezo pickups. This causes some intermodulation behavior even in hexaphonic processing; notice the tiny amount of it in the 6Appeal spectrum. But the effect is almost irrelevant, comparing to monophonic processing.

Our experiments have revealed that the crosstalk between the strings in hexaphonic pickup has to be at least around, or better less than -20dB, to catch the "tonal magic" of hexaphonic distortion. Some Roland GK-3 pickups and a RMC piezo pickup on Godin xtSA guitar, which we have checked out, deliver crosstalk performance around -30dB, which is fine for hexaphonic processing.

For sound examples, please see our webpage http://www.spicetone.com/[10]

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[7] http://www.roland.com/V-Guitar/
[8] http://www.endabates.net/academic.html
[9] http://rickygraham.com/teaching/spatial/
[10] http://www.spicetone.com/

Actually, we have found that a mix of hexaphonic and monophonic processing may have a pleasant character. That is the reason why 6Appeal has a seventh channel, which processes the monophonic sound (sound from conventional pickups of the guitar). For mixing in the mono signal, there is a Mono knob on the panel. It even lets you dial in prevailing amounts of the monophonic sound. Also, you may use 6Appeal with a conventional (mono) guitar - just connect your 1/4" plug to Mono In. Doing this automatically mutes the hex channels, but you still have to turn up Mono knob to hear the sound.

Hexaphonic distortion suits well with jazz or even folk styles, the territories that were almost out of reach with a distorted axe. Playing two or more hexaphonic guitars together, achieves string quartet like character. With a single guitar, if you have stereo amplifying system, you may pan each string over the stereo field, filling the stage panorama. Even without distortion at all, using just a clean sound from hexaphonic pickup, you will notice obvious difference in sound. With distortion added, you may get a tone similar to so called "Queen sound", specific to Brian May Queen-era guitar works.

Hexaphonic/polyphonic guitar processing has quite rich past history from late 1970s and early 1980s, mainly related to Roland Corp. Interested reader may check that out from [Wayne Scott Joness website](http://www.joness.com/gr300/index.htm)[11].

[11] http://www.joness.com/gr300/index.htm

5   The Technology behind 6Appeal

Traditional analog guitar pedals use mainly potentiometers as the sound adjusting elements. In case of hexaphonic processing one needs at least six potentiometers on the same shaft, which is hardly feasible. In the synth world the classic approach is based on so called CV (Control Voltage). This means using a single control voltage (or current) to control several parameters of your circuitry the same time. Although possible, we think the approach too expensive for a guitar pedal, even for a hexaphonic one. Think about some 8 channel analog synths, like DSI Prophet 08, which cost over $1,000.

In 6Appeal we use digital potentiometers approach instead. It is important to point out immediately that **digital potentiometers despite of their name are core analog components**. They are analog resistor dividers, where the output from the divider (like wiper of a potentiometer) is digitally controlled from microcontroller. The digital potentiometers we use have 256 steps available, which is smooth enough regulation for most cases. Good to compare with MIDI control, which in typical cases has half the number of steps (128) available. We also use analog electronic switches, which allow us to control the analog signal path from microcontroller.

As summary, **the whole signal path of 6Appeal is analog**. From input to output - we never digitize the processed signal. But, due to the use of digital potentiometers and digitally controlled analog switches we have several additional features, impossible with pure analog processors. Some of these features are shortly described below.
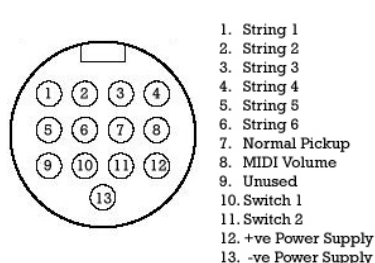
In the end of the article you may find some useful references to get more information about hexaphonic processing. We have used the term *hexaphonic* mainly keeping in mind the Roland 13pin connector standard (six channels for separate strings, one channel for mono pickup and some supporting connections). This is the standard that 6Appeal 13pin connectors match.

1. String 1
2. String 2
3. String 3
4. String 4
5. String 5
6. String 6
7. Normal Pickup
8. MIDI Volume
9. Unused
10. Switch 1
11. Switch 2
12. +ve Power Supply
13. -ve Power Supply

Although in theory one may wire all seven signal channels the way he or she would like, 6Appeal's current firmware is prepared for hexaphonic instruments support. Having said that, using all seven channels of 6Appeal for polyphonic 7 string guitar is possible with the limitation of not having the monophonic channel then.

Using less than six channels, we recommend to ground the unused inputs for better noise performance and/or mute respective unused channels in 6Appeal. From 13pin input 6Appeal supplies +/-7V to the connected equipment (like a hex guitar). This is a conventional standard (at least 100mA available). For the 13pin output connector, it does not deliver supply voltages and pins 12 and 13 are not connected.

6   Multichannel Features of 6Appeal

6.1   Root Boosts

Many hexaphonic pickups, like Roland GK-3, are often mounted very close to guitar's bridge. Thus the audio signal lacks of low frequencies even more than a typical bridge pickup of a Stratocaster guitar. To compensate that to a certain extent, we have introduced two Root Boost schematics in the signal path of each channel (6+1). One of these (Root Boost Pre) is before the distortion unit and another one (Post) is after the distortion unit.

Root Boost circuits emphasize the root notes of respective strings, making the signal richer in bass. You may switch these boosts On/Off depending on your pickup's character. These boost circuits are in the mono channel, too, where they function like a bass boost. It is possible to switch them On/Off in mono channel independently of hex channels. In many ways you may use these Root Boost switches as a kind of low frequency EQ/exciter.

6.2   Parameter Spread

6Appeal has altogether 10 potentiometers. Four of these, Drive, Tone, Level, Dry, have interconnected Spread knobs. The Spread function means applying particular parameters in different amount for a portion of strings. For instance, turning Drive Spread knob clockwise, the higher strings get proportionally stronger distortion; at the same time, the lower strings obtain are cleaner character. Turning the knob counterclockwise reverses the effect.

You may adjust the balance of sound level of the strings, turning the Level Spread knob. Using Tone Spread and Dry Mix Spread lets you adjust the tonal character over the strings.

The higher vs lower string processing shape is called Tilt. It may be changed to Smile type, which means stronger or weaker processing of center strings (Smile/Frown character). You may also find several uses of parameter spreads with Modulation Effects that are integrated into 6Appeal pedal and are accessible in advanced menus.

6.3   Processing each string in a different way

For each strings, you can set the processing to Effect (=processed) or Clean; you can also completely Mute some strings (6Appeal channels).

The Effect setting is obvious: applying current preset to the string. So is the Mute - the string is simply muted. You may find that useful when playing solos with just a few strings, for instance. The less specific Clean actually means applying Preset No 24 for the particular string - we simply expect you keep this preset clean sounding.

Strings can be also panned separately in stereo field. You may find that especially useful with a single guitar in the band, making the sound spatial. For soloing you may find mono more useful. We have prepared some automatic pan spreads (including center pan), accessible by a single menu action, though the panning can be adjusted manually, too. You can apply every single of the several modulation types separately per string.

6.4   13pin Output and Breakout Box mode

Contemporary hexaphonic processing devices do not provide 13pin outputs to daisy chain different processors. Some users have wondered, why companies are saving just a few bucks leaving this possibility out. Actually, the situation is not that simple. As the contemporary hex processors are mostly digital, the analog 13pin output would mean at least six (or seven, with mono channel) additional Digital-to-Analog Convertors, which do not come cheap, especially if quality is kept in mind.

As 6Appeal is an analog sound processor without any AD/DA converters, adding the 13pin output did not pose considerable extra costs. And, therefore, it's there, making is possible to daisy chain your hexaphonic processors just like your conventional processing pedals. There is a short 13pin cable available from Spicetone if you need it.

The truth is there are no other analog processors at the moment, only some breakout boxes and vintage gear. We in Spicetone are hoping there will be other gear soon. Besides our own ideas in development, we welcome any competitors, as we have no intention to be the monopolist of analog hex processing.

Most of the gear to process 6+1 (soundcards, mixers) uses 1/4" jack inputs. Therefore a 13pin Out is not sufficient by itself. Instead, you can set 6Appeal to output separate channels (hex plus mono) through conventional audio outputs in the back panel. Use conventional 1/4" Y cables or three Y adapters and normal instrument cables to get each channel out separately.

Our customers have stated that 6Appeal is an excellent Breakout Box, as it is active and can get strong clean gain levels. In fact the levels are strong enough so that you do not have to rely on the often noisy input preamps of your soundcard.

Just do not forget to switch 6Appeal back to stereo/mono output afterwards, when you're switching back to default stereo or mono output setup, i.e. using it with a guitar amplifier.

7   Other Features of 6Appeal

There are several other features accessible thanks to microprocessor that controls the analog circuit. There could be present in any similar device, and are not specific to hexaphonic processing.

7.1   Presets

The most apparent application of digitally controlled analog processing is having preset memories that users can freely customize. Just like in contemporary synthesizers you can save your current sound to a preset and recall it later (using encoder, PREV/NEXT footswitches and/or MIDI).

6Appeal has 24 presets available, indicated by the clock-like LED display in the center (12 Green and 12 Red presets). The Preset No 24 (Red preset at 12 o'clock position) has a special meaning: the ON/OFF footswitch toggles between current preset and the Preset No 24, which acts as a clean or bypass preset depending on your needs.

In fact, 6Appeal has six Banks of Presets, which totals number of presets available to 144 preset memory slots. We do realize that using the Banks from 6Appeal physical interface is not too easy, but it should get easier with computer control software we are working on. The Banks let you to copy and adjust the Presets for different signal sources, like different guitars, or to prepare presets for different uses (studio, live, experimental, etc.). You may also easily recall the Banks and/or Presets by external MIDI controller. In fact, every aspect of 6Appeal is covered by MIDI.

7.2   Circuit Modifications. Three Kinds of Overdrive

People often like to modify their analog processing modules. We are doing that with digitally controlled analog switches. For instance, 6Appeal delivers three kinds of overdrive/distortion, which we call Overdrive, Crunch and Fuzz. The Overdrive setting is the smoothest one. The Crunch adds some asymmetrical processing and makes even number harmonics level higher (in synth terms it takes pulse signal closer to sawtooth). The Fuzz is a doubled distortion and the strongest one in sense of distorted signal.

Our signal path is optimized for the Overdrive. Unfortunately, this means that the output level is changing when the drive type is changed. Crunch is less loud than Overdrive and Fuzz is less louder. You have to adjust output level with Level (or Filter Volume) pot. We are hoping to smooth this issue out in a firmware update.

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7.3   Stereo Filter

Due to the tonal (cleanish) character of hexaphonic distortion, we actually have made the distortion channel frequency bandwidth larger than this is typical for a traditional monophonic distortion pedals. In case you do not enjoy the large amount of higher frequencies, you may filter them out with the Stereo Filter. Please notice that the Filter affects stereo/mono outputs only and the audio signals from 13pin or Breakout Box setup output are not affected.

The Filter is actually a resonant second order low-pass filter (12dB/octave). You can use it for creative purposes, too. For instance, you may want to take two Frequency knobs slightly apart and get Resonance up, giving a very pronounced resonant sound. That is also the reason we have two separate Frequency pots, which is not typical for this kind of filter. In fact, you may use the Filter also as a first order filter, keeping one of the Frequency knobs at maximum, or like two serial single order (pole) filters. Just be careful with the Resonance knob, as you may get to the territory of self-oscillation. We have not limited that, so that you have extreme sound sculpting possibilities.

You may also modulate filter parameters, getting automatic wah-wah type sounds.

7.4   Modulations

A special feature of 6Appeal, available thanks to the use of digital potentiometers, is modulations and LFO effects. This takes us to the territory of analog synths, giving boundless possibilities. To get these options running, you really have to dig the 6Appeal User Manual[12].

6Appeal has two LFOs (low frequency oscillators), a 24-step sequencer and an envelope controller. They all are realized by software in the microcontroller, which is controlling the digital pots that rule the analog circuit. This means that all the modulation possibilities in 6Appeal are some pieces of microcontroller software. This is a typical approach for nowadays hybrid synths, for instance. Just that they tend to use CV control instead of digital pots.

Our way to control the modulations has some limitations. For instance, the modulations never can be as smooth as you get from a Moog Voyager synth, for instance. But the monophonic Voyager costs many times more than polyphonic (6+1 "voices") 6Appeal. Also, although we have tried our best, both in hardware and software design, to avoid switching glitches, there always is some level of switching noise present. In most cases it is inaudible. We consider the Modulations as a bonus feature, that does not much affect the price of the module and works surprisingly well in most cases. If you like the Modulations, feel free to use. If that is not your cup of tea, please skip the feature.

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[12] https://cdn.shopify.com/s/files/1/0253/7907/files/6_APPEAL_-_User_Manual_1.0_3e03aac2-e93a-4a71-9da7-9adfbc504c55.pdf?1048

At this point the envelope control has not many applications yet as 6Appeal has no internal envelope generator. You can connect another module that detects note picking, for example Roland GR-55, to 6Appeal by MIDI, and thus have envelopes working. We do continue on the matter, both in the sense of hardware and firmware.

7.5   MIDI Control

Almost all 6Appeal parameters can be controlled externally by MIDI commands. We use CC messages for continuous parameters and Note On messages for stepped parameters (On/Off type or some other 2-4 level controls).

For instance, any MIDI controller pedal can be used as an expression pedal to control any single parameter of 6Appeal. Even more, with Pitch Bend, Modulation and Breath controls you are able to control groups of parameters together; main parameters (like Drive, Tone, Level, etc.), string panning in stereo field and/or Filter parameters (similarly as you control Modulations). Using more complex controllers, the possibilities are endless. If you are controlling your pedalboard with MIDI, it is a very easy to include 6Appeal to the control center.

Even more, as 6Appeal has a MIDI Out port, you may use 6Appeal as a MIDI controller itself. There is a user interface menu, which gives you possibility to send out CC messages and some MIDI messages with every preset, so you can control your other MIDI devices. Please see the User Manual[13]. The simplest use of MIDI Out is to use it as a MIDI Thru port.

7.6   Firmware Updates

As 6Appeal is a digitally controlled hardware, we are able to provide firmware updates. 6Appeal has a mini USB connector, which can be used to connect the device to a computer for this purpose.

At this point USB port does not have any other use, but we have some other ideas for it, too. Please be assured that we have plans for firmware development and we hope to surprise you in that regard with some unique possibilities.

Feel free to send us your ideas, so we can use these, with your permission, either for software updates or future hardware development.

Along with the white paper, a series of short demo videos are published in Youtube.

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[13] https://cdn.shopify.com/s/files/1/0253/7907/files/6_APPEAL_-_User_Manual_1.0_3e03aac2-e93a-4a71-9da7-9adfbc504c55.pdf?1048

8   Demonstration Videos

First of the videos demonstrates analog polyfuzz, also called hexaphonic distortion, with a Roland GK-3 divided pickup mounted on the bridge of a Fernandes guitar. The 6Appeal pedal is used for a panning effect, too:

https://www.youtube.com/watch?v=q_DDOnc7DCA

Second video shows a how to correct the sound of a Roland GK-3 pickup in analog domain. Mounted by guitar's bridge, it tends to lack lower frequencies, but can be beefed up with analog root boost circuits in 6Appel pedal:

https://www.youtube.com/watch?v=eONehL3h5kc

Third video demonstrates a Godin "Synth Access" equipped guitar with analog polyfuzz, stereo panning applied in 6Appeal. A selective amount of drive and dry signal mix, and some modulation is used:

https://www.youtube.com/watch?v=fz18rTtdUbU

Fourth video is focused on making and saving a custom preset for the microprocessor controlled 6Appeal pedal:

https://www.youtube.com/watch?v=9EUbO59OO_Y

This a comparison video of hexaphonic 6Appeal and classic Big Muff distortion pedal by Electro Harmonics.

https://www.youtube.com/watch?v=nw-RMAnBccg

The separate signals from multichannel pickup can be recorded to soundcard and processed in many ways. The next demo show the clean, unprocessed sound, and post processed sound with gates, EQ, panning, compression, flange, phasing, amplifier and room convolution models applied.
https://www.youtube.com/watch?v=O5ftv8fq2Fk

The last video of the series shows Mart Pauklin jamming with 6Appeal, using an ESP Viper equipped with a handwound hexaphonic pickup by luthier Halvo Liivamägi.

https://www.youtube.com/watch?v=X32e1b4jJ3g

9   Some references

Vintage Roland Guitar Synthesizer Resource by Wayne Scott Joness. Technical and background information about Roland analog guitar modules and related guitars. Good list of links to other sites.

Why Polyphonic (Hexaphonic) Distortion? by Matthias Grob - a lot of useful information both from historical and technical point of view.

Hexaphonic Guitar by Enda Bates, a musician, composer, producer and academic based in Dublin, Ireland. A lot of information from spatial production point of view, including academic articles and his PhD thesis.

Signals Under Test by Ricky Graham, a musician and academic in Stevens Institute of Technology, USA. Spatial music, interactive music systems, software instrument.

Roland V-Guitar has information about their contemporary digital hexaphonic processing equipment. Also about GK pickups.

Cycfi Research is an Open Source software and hardware company based in Manila, Philippines, producing fiber-bamboo electric and electronic guitars, acoustic synthesizers and state-of-the-art digital signal processing systems and active polyphonic pickups; most notably Neo series pickup system. There's valuable technical and scientific info and drawings on the website, too.

Many thanks for reading!

If you have any questions, please find our contacts on www.spicetone.com.