SEPTAR: Audio Breakout Circuit for Multichannel Guitar

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ABSTRACT

Multichannel (or divided) audio pickups are becoming increasingly ubiquitous in electric guitar and computer music communities. These systems allow performers to access signals for each string of their instrument independently and concurrently in real-time creative practice. This paper presents an open-source audio breakout circuit that provides independent audio outputs per string of any chordophone (stringed instrument) that is fitted with a multichannel audio pickup system. The following sections include a brief historical contextualization and discussion on the significance of multichannel audio technology in instrumental guitar music, an overview of our proposed impedance matching circuit for piezoelectric-based audio pickups, and a presentation of a new open-source PCB design (SEPTAR V2) that includes a mountable 13-pin DIN connection to improve compatibility with commercial multichannel pickup systems. This paper will also include a short summary of the potential creative applications and perceptual implications of this multichannel technology when used in creative practice.

Author Keywords

Septar, Multichannel, Breakout, Chordophone, MIDI, Hexaphonic.

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing.

1. A HEXAPHONIC HISTORY

For decades, instrument designers have developed multichannel audio processing applications for music composers, producers, and performers. Rolf Spuler's[1] Paradis guitars (1983) are fitted with multichannel audio pickups, similar to Moog's guitar product line fitted with Graphtech audio pickup systems. Mathons (Grob and Butler 2004) have produced a number of 'polyphonic' VST plugins for multichannel guitar pickup systems. Keith McMillen[2] has produced an onslaught of multichannel audio applications for violinists and guitarists. Miller Puckette's Smeck[3] (2007) system gained popularity in the Pure Data (Pd) community, allowing guitarists to parse and process each string of a guitar fitted with a multichannel pickup.

Spicetone (Afanasjev et al. 2014) introduced the 6-Appeal for hexaphonic (6 string) electric guitars, boasting independent distortion and filter modules per string in one consolidated audio effects hardware unit. Cycfi Research's[4] (deGuzman 2015) Neo pickups and acoustic synthesis products clearly demonstrate significant developments in this field, which will undoubtedly prove useful for string players operating in the experimental music sphere.

2. MULTICHANNEL GUITAR MUSIC: A PARADIGM SHIFT

Multichannel guitar technology is often touted as having emerged in the creative musical practices of the early 1970s. During this period, guitarist John Martyn used multiple acoustic guitar pickups to capture audio from the strings and the body of an acoustic guitar independently and concurrently for real-time audio effects processing [12]. His approach produced rich and contrasting textural and rhythmic structures from a single instrumental sound source through a relatively simple technology. Composer and educator Enda Bates composed a work for 'hexaphonic' guitar in 2008, using individual audio streams per register as a foundation for three musical sequences: predefined tuning, interval, and spatial location structures [1]. Arguably, this approach to performing and composing guitar music is a radically refreshing divergence from the popular usage of MIDI guitar technology.

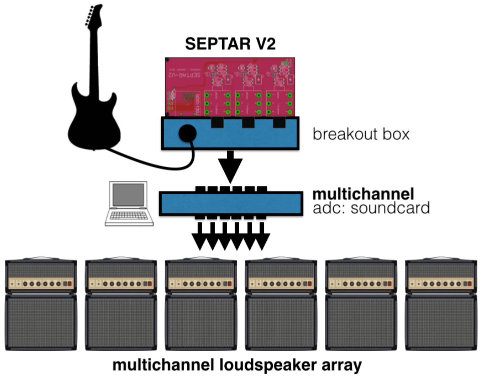

Figure 1: Typical signal flow of multichannel systems when used with an electric guitar and audio breakout device.

This type of multichannel audio pickup technology is largely based on standardized MIDI guitar pickup systems, such as Roland's GK, GR, and VG product series[5], RMC's Polyphonic Bridge Pickups[6], and Graphtech's piezoelectric-based Ghost Modular Pickup System. Each system utilizes a standardized 13-pin DIN connection[7] in conjunction with individuated pickups that capture audio signals for

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[1] http://bit.ly/1GYrZHz
[2] http://www.keithmcmillen.com
[3] http://msp.ucsd.edu
[4] http://www.cycfi.com/
[5] http://www.roland.com
[6] http://www.rmcpickup.com
[7] http://bit.ly/1CW8qtj

each string of an instrument (via pins 1 to 6 or 7 of the DIN connector). Conventionally, these systems track pitch and amplitude information, which is then converted into the standardized MIDI note paradigm as a means to trigger banks of synthesized instrumental tones. Our contention is that this approach barely realizes the potential of a fairly simple music technology, particularly given the increasing interest in spatial music composition within the electroacoustic music community[8]. Recent research projects within the computer music community combine multichannel audio technology with breakout audio circuits to parse and analyze individual instrumental registers for pitch, amplitude, and timbral information for gesture recognition applications and for the real-time parametric control of complex musical processes [2,3,4,8,13]. An important advantage of using individuated audio outputs is the improved tracking accuracy due to reduced crosstalk between adjacent strings [4]. While the aforementioned commercial breakout devices are refined in many respects, one large drawback of these devices is the high commercial sale price, which drastically reduces accessibility. In part, this served as motivation for the development of an affordable open-source breakout audio board design. SEPTAR V1 emerged in 2011 with a small number of boards being produced for beta testers[9]. The boards were accompanied by audio effects software programmed in Pd [4]. The following section will present an overview of SEPTAR V1.

3. SEPTAR V1 – ORIGINAL DESIGN

SEPTAR V1 is based on a Junction Field Effect Transistor (JFET) impedance conversion circuit authored by Harding in 2010 [4]. The circuit is primarily designed to function with piezoelectric pickup systems but it is compatible with magnetic systems, such as Roland’s MIDI pickup series. Piezoelectric transducers used in sensor arrangements are considered to be ultra-high impedance devices and, as such, require approaches to amplification and load resistance that minimize signal loss. The failure to present a suitable load resistance in the piezoelectric amplification circuitry results in low-end frequency loss referred to as the “loading effect”[10]. Typically, input impedance for the amplification of piezoelectric sensor signals should be as high as possible but in practical applications figures vary between 1MΩ and 10MΩ[11].

In designing SEPTAR V1, Junction Field Effect Transistors were the most suitable choice for amplification as these devices feature naturally high input impedances[12], they are available in low noise format, and they can also be operated at very low current[13] leading to extended battery life in comparison to equivalent op-amp based designs [5]. In addition, JFETs provide extremely high resolution and are widely regarded in both electronic engineering and audiophile circles as offering superior sonic performance in comparison to BJT or op-amp based circuits[14] (also, see footnote 12). Each channel operates as an independent *signal buffer* or *source follower*, the function of which is a provision of impedance conversion, without significant alteration of gain[15]. Conversion from high output impedance of the piezoelectric sensor element(s) into a low output impedance[16] of the *source follower* permits further amplification via traditional high impedance guitar *stomp-box* processors or traditional line input stages, which generally have input impedances of approximately 1MΩ and 10kΩ respectively[17] [9]. In addition, the relatively low output impedance aids in minimizing signal loss over extended cable lengths.

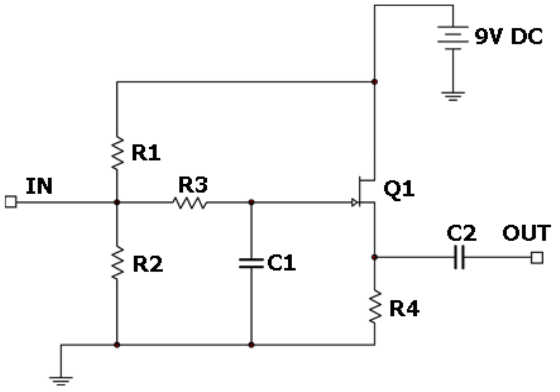

Figure 2: SEPTAR schematic simplified.

Figure 2 outlines a single *common drain source follower* [7] or *buffer* channel of SEPTAR V1. Resistors R1 and R2 (2.2MΩ 1%) perform two important functions. Collectively, they set the input impedance of the circuit to an appropriately high value of approximately 1.1MΩ in order to minimize the negative impacts of the aforementioned loading effect. Secondly, these resistors collectively form an equal voltage divider, allowing the operating point of the JFET to be set such that the gate is biased at half the supply voltage[18], which is approximately 4.5V DC. Resistor R3 and Capacitor C1 collectively form a First Order Low-Pass RC filter with a corner frequency of approximately 194kHz, with values of 10kΩ and 82pF respectively. The function of which is to reduce the sensitivity of the circuitry to RF interference. The corner frequency of this filter may be reduced at the builder’s discretion. For example, the substitution of capacitor C1 with a value component value of 680pF would result in an adjusted corner frequency of approximately 23kHz. The N-Channel JFET Q1 of type J201 is selected for its low noise and low operating current specifications[19] and provides the required impedance conversion functionality. Each channel consumes a maximum of 1mA per channel at a voltage of 9V DC. A single PP3 type battery provides power.

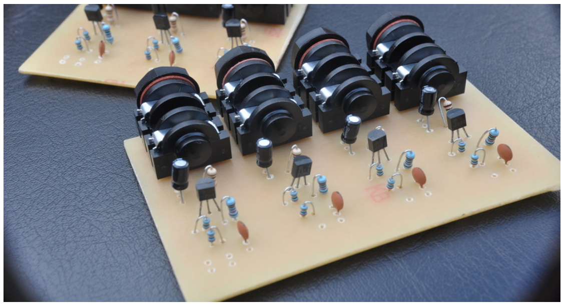

Figure 3: SEPTAR V1 final build by beta tester, Andy Butler in 2011.

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[8] For example, the Cube at Virginia Tech (SEAMUS 2015)

[9] Beta test reports are available in [4]: http://bit.ly/1Q2aEjD

[10] http://bit.ly/1OorFB6

[11] http://bit.ly/1OosVnN

[12] http://bit.ly/1NZSBfq

[13] Current consumption per channel: Min 0.2mA, Max 1.0mA.

[14] http://bit.ly/1FTtzoD

[15] Gain is reduced by a factor of approximately -0.915dB.

[16] Measured at 560Ω for the J201 JFET in this test.

[17] http://bit.ly/1O1QO9S

[18] The values of R2 and R3 are matched within 1%.

[19] http://bit.ly/1CW8YiN

Following a suggestion by beta-tester Butler [4], SEPTAR V2 adopts a pseudo-balancing technique in order to improve output compatibility with receiving balanced equipment[20]. The major benefits of this approach include an improved noise rejection and more efficient transmission of energy from source to load[21] [10]. To efficiently reject interference that might propagate onto two signal wire connections it is necessary that the interfering (noise) source induces an equal interference voltage on both signal lines simultaneously, hence why it is considered to be *common-mode*. This can only be achieved if both signal wires present identical impedances to ground. In order to achieve this, one must measure the output impedance of the circuit in question and balance this impedance with a matching resistor from the cold wire to GND. The cold wire presents the same impedance to ground as the hot wire and thus ensures correct common-mode rejection. The adoption of this approach has the benefit of improving frequency response while reducing build cost compared to a transformer-based output balancing alternatives. It also allows for a reduction in component count versus an electronic or fully differential circuit.

4. SEPTAR V2

4.1 A New PCB Design

SEPTAR V2 presents a new PCB design, which includes a right-angled onboard 13-pin DIN socket for ease of build and use, as recommended by our beta testers[22]. It also incorporates the impedance balancing option illustrated below in Figure 4.

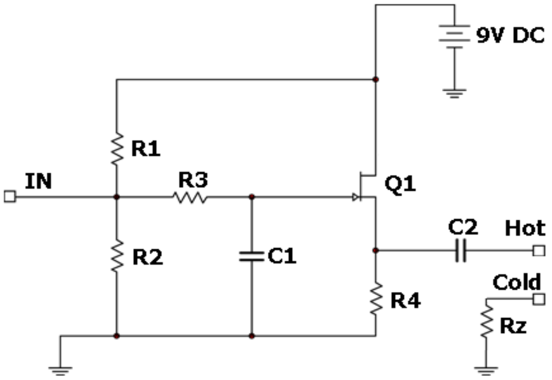

Figure 4: The updated schematic to include impedance-balancing resistor Rz.

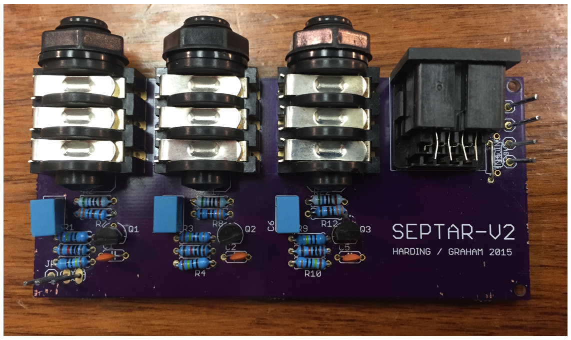

Figure 5: SEPTAR V2 - A new PCB designed in EAGLE.

4.2 Technical Analysis of Circuit

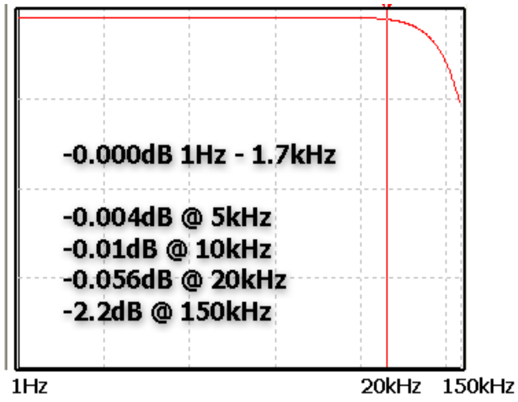

Figure 6: Frequency response analysis plot.

The frequency response of a single channel is shown in Figure 6. From 1Hz – 1.7kHz the response is considered entirely flat with no notable gain reduction beyond the aforementioned figure. A further reduction in gain of -0.056dB is present between 1.7kHz to 20kHz and between 20kHz and 150kHz gain reduction is in the order of -2.2dB.

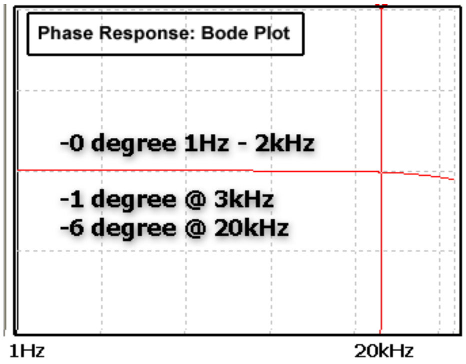

Figure 7: Phase Response Analysis Plot.

Although human sensitivity to phase distortion is not particularly acute [6], minimal phase distortion should be the goal in any circuit in order for source signals to be captured as accurately as possible. The phase response characteristics are stable for SEPTAR, as depicted in Figure 7. Two audio recordings demonstrate an RMC guitar pickup system with [audio example 1][23] and without [audio example 1][24] the SEPTAR. Note the difference in the distribution of power across the frequency domain. Overall, the new circuit design provides a more balanced frequency response between registers when performing soft and loud musical passages. Without the SEPTAR, low and high frequency signals are unbalanced in terms of amplitude. SEPTAR adds more clarity and boosts high frequency detail.

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[20] http://bit.ly/1G4pzY3
[21] http://bit.ly/1yELi69
[22] http://rickygraham.com/research/septar/
[23] https://soundcloud.com/spatialschemas/rmc-septar-v1
[24] https://soundcloud.com/spatialschemas/rmc-only

4.3 Musical Effects and Applications

Initial tests with the divided pickup systems revealed an immediate reduction in intermodulation (IM) distortion when each string is subjected to high gain effects processing. The results stand in stark contrast to the roughness attained by monophonic magnetic guitar pickup systems. Sabolotny (2014) has written extensively on these differences between monophonic and multichannel pickups when using distortion effects processing, including comparisons between Electro-Harmonix's Big Muff monophonic distortion unit and Spicetone's 6Appeal polyphonic distortion unit [11]. In short, the summed signals of a monophonic pickup system produce inharmonic artefacts through nonlinear interactions between signals, which musicians may use to convey dissonant musical effects in their works. By contrast, individual distortion modules per string of any given chordophone will accentuate more tonal or harmonic content through a linear distortion process, mitigating inharmonic intermodulation distortion events commonly experienced with a monophonic audio pickup. Audio examples of the monophonic DiMarzio PAF Pro magnetic Humbucker guitar pickup [audio example 3][25] and Graphtech's multichannel (or 'hexaphonic') Ghost Modular Pickup System [audio example 4][26] demonstrate such differences in timbral structure when both pickup systems are subjected to the same distortion effects stages.

The individuation of registers opens a host of possibilities for the performing electronic musician, allowing for complex melodic counterpoint that can be parsed by the listener with greater ease due to the independence of each audio channel. The suitability for spatial audio applications should be clear from the previously noted musical examples by Bates (2006 - 2009, 2010) and our own audio examples. Complex rhythms between adjacent registers may be spatialized to encourage stream segregation between what would otherwise be perceived as an integrated harmonic structure, as demonstrated by [audio example 5][27] and [audio example 6][28]. These effects potentially provide a basis for unconventional chordal and rhythmic groupings. Overall, one can manipulate pitch, timbral, spatial, and rhythmic configurations per register, foreground timbre and spatial structures beyond nuance, all while utilizing a single instrumental source as a tool for real-time parametric control.

5. CONCLUSION & FUTURE WORK

A refocusing of MIDI hardware for multichannel audio composition is seemingly intuitive and appropriate for the creation of electronic and electroacoustic music. We have presented the SEPTAR audio breakout as an affordable printed circuit board design compatible with the majority of divided or individuated audio pickup systems available on the commercial market. This multichannel audio breakout design permits one to carefully sculpt the sonic attributes of each register of their instrument. This system will permit the manipulation of pitch, timbral, spatial, and rhythmic configurations per string of any chordophone through digital signal processing, allowing a solo instrumentalist to foreground timbre and spatial structures beyond the conventional design of their instrument. SEPTAR V2 is available through OSHPark[29]. Future iterations will accommodate more audio channels for guitar pickup systems designed for additional registers.

6. REFERENCES

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[25] https://soundcloud.com/spatialschemas/ex1

[26] https://soundcloud.com/spatialschemas/ex2

[27] https://soundcloud.com/spatialschemas/ex3

[28] https://soundcloud.com/spatialschemas/ex4

[29] https://oshpark.com/profiles/SEPTAR