White Paper on:

SPEAKER LEVEL SIGNALS: SPLITTING and CONTROL

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1.0 INTRODUCTION

Transformer Free Architecture

Transformer free architecture is important to stereo reproduction because it allows control and splitting of stereo signals with minimal sound quality degradation. Transformer free architecture is not a "new" technology. It was developed and perfected in the 19th century. Exciting recent advances in ceramic materials have revitalized this technology making its use in multi-room stereo and custom installations advantageous.

2.0 Defining Speaker Level Signal Splitting and Control

2.1 **Defining Speaker Level**

The so called "speaker level" signal in the audio industry is defined as the signal emanating from an audio frequency power amplifier, to a low impedance (less than one ohm to a maximum of about 20 ohms) speaker or speaker system. The characteristics that differentiate a "speaker level" signal from other audio signals such as "line level" or "microphone level" is that "speaker level" voltage is relatively high; normally up to a maximum of about 65 volts (RMS) and the current flow is much higher; up to 15 amperes (RMS) or more. IT IS THE HIGH CURRENT FLOW OF SPEAKER LEVEL SIGNALS THAT MAKE THEM DIFFICULT TO DEAL WITH. A constant voltage system such as a 70-volt audio system (commonly used in commercial and industrial installations with
ceiling speakers) uses significantly lower current levels (rarely over two amperes) than a "speaker level" system.

2.2 **Speaker Level Signal Splitting**

WHEN A STEREO AMPLIFIER POWERS MORE THAN ONE PAIR OF SPEAKERS THE OUTPUT OF THE AMPLIFIER REQUIRES "SPEAKER LEVEL SIGNAL SPLITTING.

In an ideal multi-room stereo speaker installation, a separate amplifier that is controlled from the room with the speakers powers each pair of speakers in each room. In practice it is generally unnecessary to require an amplifier for each pair of speakers for a variety of reasons, including:

2.21 **Common volume rooms** (example: living room attached to dining room) should listen to a common program, so each room does not generate background noise for the other room.

2.22 **Multiple speaker zones** with one to two programs (in a home with eight speaker zones and two occupants it is generally unnecessary to have 8 different programs running simultaneously).

2.23 **Economy of scale** (an amplifier powering more than one pair of speakers makes a system more economical).

2.3 **Wire Methods of Speaker Level Signal Splitting**

Speaker level signal splitting can take place in one of three standard forms including parallel, series, and combinations of parallel and series.

2.31 **Parallel Speaker Wiring**

The preferred method to obtain top-quality sound and reliability when signal splitting is to wire speakers in parallel. This means that the current flowing in one speaker (see figure 1) does not go through any other speaker (i.e. each current path is independent and flows to and from the amplifier only). The major advantage to parallel speaker wiring is that each speaker will sound their best (even if different kinds of speakers are used in parallel). The major drawback of parallel wiring is that virtually all amplifiers and receivers in common use has a minimum recommended impedance load (usually 2-8 ohms) so the number of pairs of speakers that can be wired in parallel to an amplifier is usually limited to two pairs. In order to connect more than two pairs of speakers in parallel to a conventional stereo amplifier or receiver, the speakers must be high impedance (typically 16 ohm or more and generally with an impedance matching transformer) and/or some form of current limiting may be used or a stereo speaker interface (sometimes called "load center") may be used (see note **1**).

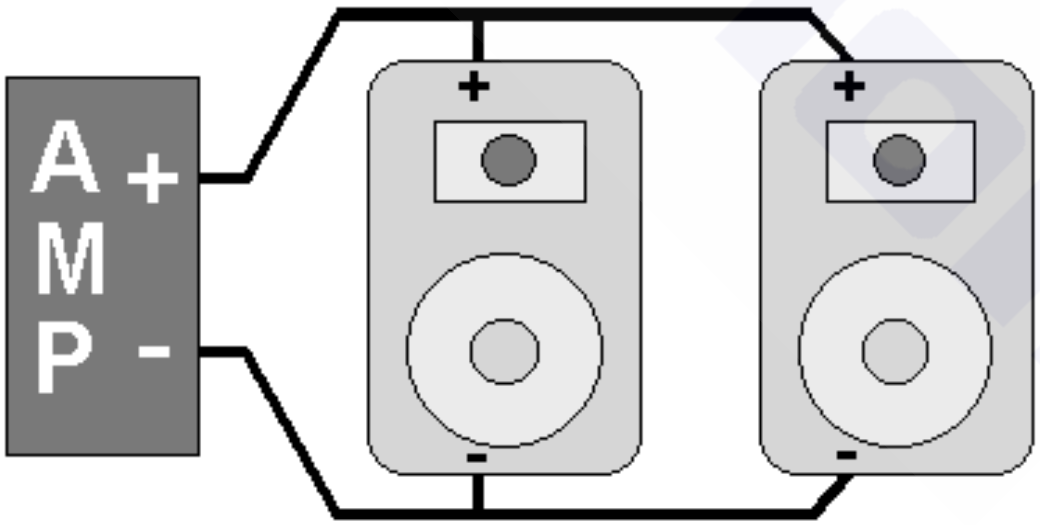

Fig. 1 **Parallel Speaker Wiring**
Note: Left channel amplifier, speakers and connections shown. The two speakers can be different models and both will sound their best.

2.32 **Series Speaker Wiring**

Series speaker wiring (see figure 2) is an effective method to increase speaker system impedance to safe operating levels for amplifiers. The advantage of series speaker wiring is that many speakers can be used on one amplifier without causing amplifier problems associated with low impedance connections. SERIES SPEAKER WIRING HAS SOME DRAWBACKS. Dissimilar speakers should not be used in a common series line because both speaker types will not sound their best (their impedance curves are not identical and each will be attempting to draw excessive current at frequencies that the other speaker
won't permit). As well, stereo room volume controls should not be used because when one room's volume control is turned off, the speakers in the other room will also be shut off (and vice versa). Series speaker wiring always lowers system reliability and may lower the overall power available from an amplifier.

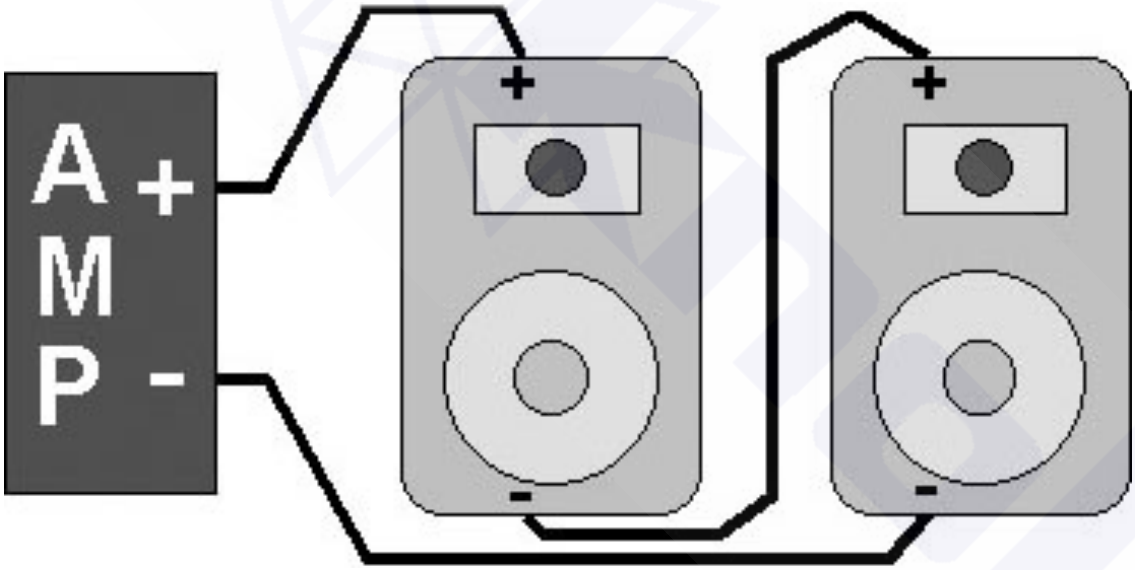

Fig. 2 **Series Speaker Wiring**
Note: Left channel amplifier, speakers and connections shown. The two speakers must be identical models to sound acceptable. Always avoid using speakers with different woofer sizes when series wiring.

2.33 **Combination of Series and Parallel Speaker Wiring**

Combining series and parallel speaker wiring (see figure 3) usually emphasizes the drawbacks of both methods and always lowers
system reliability. In many cases, this method is the only reasonable method possible to connect several speakers to one
amplifier (sound quality with series and parallel wiring is generally considered superior to using impedance matching transformers including 70-volt line transformers). Only identical speaker models should be wired in the series portions or branch and with a maximum of one volume control or off-on switch for each parallel branch.

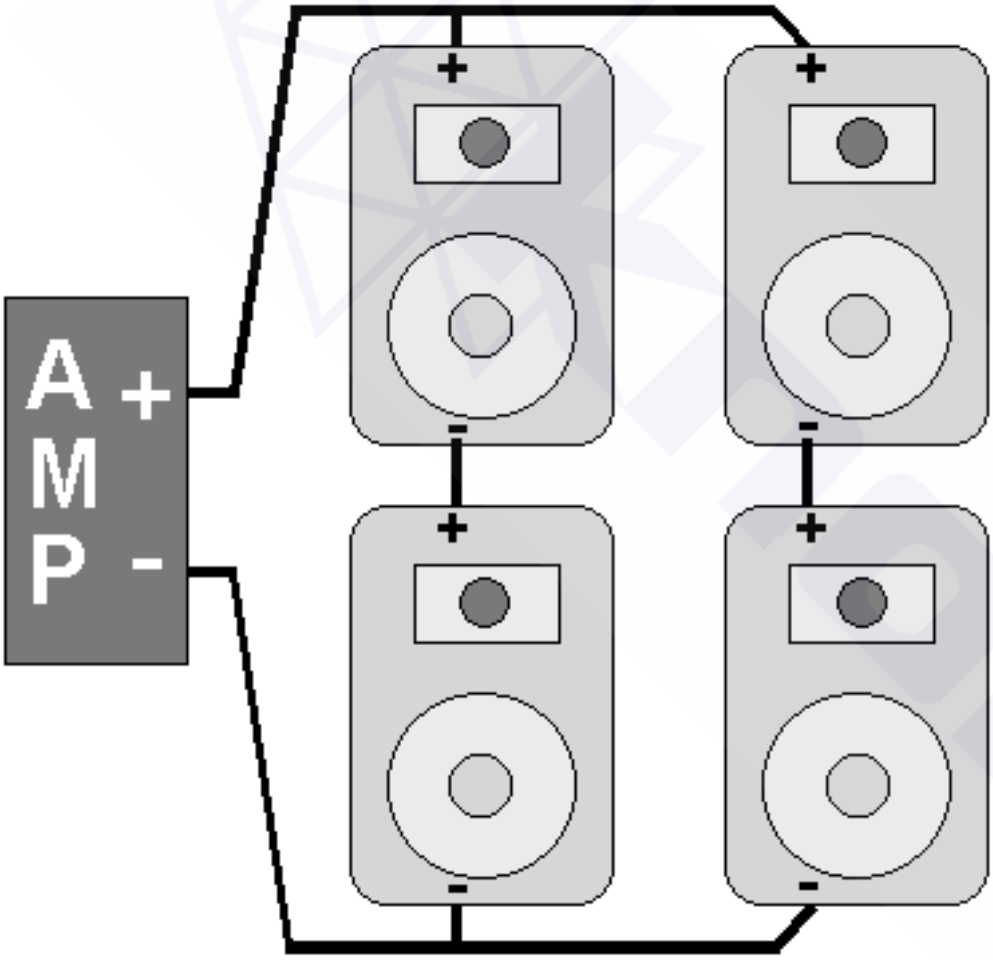

Fig 3**: Series and Parallel Wiring**

Note: Left channel amplifier, speakers and connections shown. The two "A" speakers need to be the same model. The two "B" speakers need tobe the same model. "A" speakers do not have to be the same type as the "B" speakers. Polarity is very important when wiring as the bass could be adversely affected. If all four pairs of speakers are 8 ohm and wired as in fig 3, the resulting amplifier load is 8 ohms.

3.0 Popular Methods to Split and Control Speaker Level Signals

3.01 **Speaker Level Signal Splitters**

Speaker level signal splitters are designed to split signals to multiple pairs of speakers and/or room volume controls (usually more than two pairs).

3.02 **Speaker Level Volume Controls or Attenuators**

Ideally with most multi-room stereo speaker installations speaker output is controlled from inside the remote room (a remote room being defined for the purpose of this paper as a room without a resident amplifier and/or preamplifier). The simplest room speaker control is an on-off switch. Speaker volume controls (passive) attenuate speaker level signals to various levels (some never allow direct amplifier connection). Some speaker volume controls can turn the sound at the speakers fully off. The ability to turn speakers fully off is very important in some circumstances, such as when a person wishes to turn off bedroom speakers to sleep.

3.1 **Conventional Transformers**

Transformers with primary and secondary windings are not commonly used for speaker level signals as their cost can be prohibitive and except in rare circumstances have no benefits over other designs.

3.2 **Autotransformers**

Autotransformers (or autoformers) are similar to conventional transformers except they only have a primary (one) winding with multiple "taps". Autotransformers are popular for both splitting and control of speaker level signals (many popular brands of speaker level volume controls are autotransformers) because they can be inexpensive and effectively control volume levels. Their major drawbacks are that because they are a transformer they cause a nonlinear phase shift, their amplitude response is not linear at all frequencies (usually drops out high frequencies at higher signal levels). The core limits dynamic range and winding size, so if a large dynamic range is required (typical for CD and other digital audio sources), a bulky expensive core and winding assembly is required (times two for stereo). Autotransformers that are reasonably linear with a broadband high dynamic range are generally impractical for common use due to size and cost.

3.3 **Resistive "V-Pads"**

Resistive "V-pads" are devices with variable input and output impedances (with respect to the amplifier) depending on the load impedance connected to the pad and in the case of "V-pad" volume controls, the volume setting. All Knoll transformer free volume controls are Resistive "V-pads". Resistive "V-pads" sound great because the phase shift is minimal, the amplitude response (commonly called frequency response) is ruler flat (linear) up to and beyond its power rating and heat generation is minimal in the lower and off positions as the V-pad input impedance is high in the lower and off positions. Resistive "V-pads" have two drawbacks. They can lower the speaker-damping factor and can generate heat (causing a device temperature rise). Speaker damping factor is a calculated result, indicating the ability of an amplifier to damp energy (technically back EMF) reflected from a speaker. In very high power low frequency applications such as with 18" disco sub woofers, damping factor is important, so "V-pads" or any other type of control should not be used and those speakers should always be directly connected to the amplifier. In virtually all other cases damping factor isn't a significant issue and can be ignored (see note 2). Heat generation in "V-pads" can be a major concern. The major benefit of the "V-pad" over the "L-pad" is that when the volume control is turned to a low or off setting, the amplifier sees a high impedance (typically over 200 ohms). With the volume control knob in the lower and off positions only very small amounts of power are turned into heat by the volume control (typically less than 1/2 watt), which is not even noticeable when touched. Recent advances in ceramic materials allow a much higher device power rating than previously possible as these special resistors store heat better and don't allow fire threatening fast temperature rises (see note 3).

3.4 **"L-Pads"**

The "L-pad" is a resistive device with two variable impedance pads. It has constant impedance with respect to the amplifier, usually 8 or 16 ohms. "L-pads" were developed to control the output level of tweeters and midrange speakers without the high current typical of woofers. The "L-Pad" sounds great, has minimal phase shift, is very linear up to its power rating but has a major drawback, which virtually eliminates the “L-Pad” from use in multi-room and custom installation situations. Because the "L-pad" is a constant impedance device, at lower volume settings the "L-pad" converts all of the energy not sent to the speakers into heat which can be considerable. Even in a moderately powered system, "L-pad" reliability is low and lifetime is short. Worse yet, there is a fire hazard present when using "L-pads" to control full range speaker level signals.

3.5 **Current Limiting**

Current limiting speaker level splitters are popular. This method usually puts all speaker outputs in parallel, normally with an on-off switch for each speaker zone. At very low signal levels this is the best method of speaker level splitting as nothing interferes with the signal at all. At higher volume levels, when most or all zones are turned on, current limiting is required so the amplifier doesn't shut down or self-destruct. When current limiting occurs it reduces the dynamic range, taking the "punch" out of digital recordings. In some cases, limiting is audible when the limiter turns on and off, distorting sound quality. Some manufacturers allow the limiting to be defeated, which can destroy the amplifier and potentially be a fire hazard.

4.0 Physical Size Benefits of Transformer Free Architecture

Transformer free architecture does not rely on active components or transformers. Relatively small "finless" elements are used specifically selected for their ability to resist fast temperature spikes. A pair of wide bandwidth 300 watt RMS transformers suitable for quality multi-room speaker level splitting have a minimum of three to five inches thick and will weigh 15 kg (33 lb) or more. The Knoll Transformer-Free™ SI1x6 stereo interface, using its 300 watt per channel Transformer-Free™ design is less than two inches thick (including the chassis) and weighs only 6 lbs (see fig. 4). This makes installations easier with more component space available in a rack and best of all sounds better than transformer types. Transformer-Free™ volume controls have the same "small" features. Autotransformer volume controls need to be physically large to have a large dynamic range. Virtually any brand that is large enough to sound acceptable is too big to fit in an electrical junction box (some even have a depth larger than the standard stud size of 3-1/2" so can't be easily mounted). The Knoll transformer free VC120 volume controls are only 1-1/4" deep and one "gang" wide making them very easy to install.

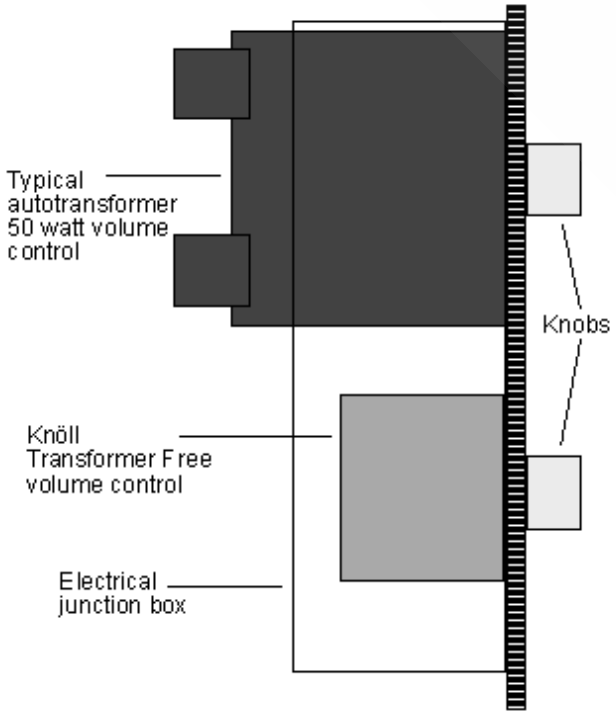

Fig 4: Size difference of Transformer versus Transformer Free Stereo Volume Controls (top view)

5.0 Sound Quality of Transformer versus Transformer Free

5.1 Theory

Linear (flat) frequency response, linear phase response and linear dynamic range are goals we strive for (recordings, amplifiers, signal processors etc. are all designs based on this assumption). Transformers are a type of inductor or "choke" which is by definition a nonlinear device and is used extensively in audio to limit high or low frequency access to speakers and signal processors (see figure 5). Nonlinear means that the frequency response is not "flat" at all power levels (it may measure flat to 20 kHz at one watt but will not measure flat at full power rating). Transformers also change the phase response with respect to frequency (this changes sound quality particularly in the mid and upper frequency bands where speech is present). Transformer free interfaces and volume controls do not have either of these inherent flaws, as they are purely resistive and therefore by definition linear in both amplitude (flat frequency response up to maximum power rating) and phase response.

5.2 Discussion and Testing Speaker Level Volume Controls

When designing our patent pending stereo volume controls, we purchased, tested and compared all major brands available.

5.21 Sound Quality at Highest Volume Control Setting

At the highest volume control setting all brands of volume controls we tested sounded pretty much the same as they directly connect the speakers to the amplifier. The only exceptions are the Elan volume control and the Russound E-Z match attenuator which always sends the signal through its autoformer giving it the poorest highest volume control setting sound quality than all others tested.

5.22 Sound Quality at Low to Mid Volume Control Settings

When comparing the sound of speakers connected to a typical autotransformer room volume control at a low to mid volume setting to an amplifier at a low setting, it was easily apparent that the volume control is affecting the sound throughout the entire spectrum. Different brands were found to affect sound quality to varying degrees.

When comparing the sound of speakers connected to Knoll VCS95 and VC120 Transformer-Free™ volume controls at a low to mid volume setting to an amplifier at a low setting, there is no appreciable sound quality change. In a blind test of the transformer free VCS95 volume control versus the best selling transformer volume control both at mid level settings with a Luxman R-117 amplifier turned up to a reasonably high level, every musical critic could pick out the better sound quality and preferred the Transformer-Free™ volume control (bass output and high frequency are the two areas affected most).

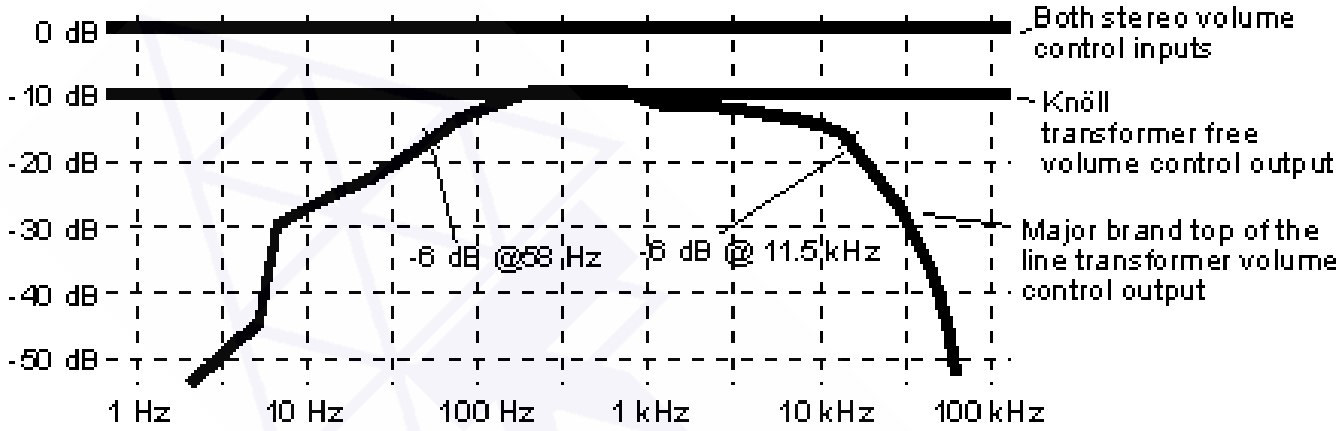

Fig. 5 **Volume Control Frequency Response**

With identical paralleled inputs and 8-ohm output loads, the -10dB attenuation output frequency response of a Knoll transformer free vs. a top-quality autotransformer volume control is shown.

6.0 Conclusions

6.1 Smallest Size

Custom installation and multi-room systems are normally designed for low visibility. The relatively small size of Knoll transformer- free volume controls and interfaces make them easier and therefore more cost-efficient to install. Knoll interfaces have a low height so more components can be placed in a rack. Knoll stereo volume controls are so small that electrical junction box (J-box) backs don't have to be cut out to make them fit. From a sight line point of view they only take one "gang" or position of horizontal width (even the
highest power model VC120).

6.2 Highest Power Rating

As transformer free designs don't depend on active components or heavy bulky transformers, ultra high power designs have emerged. When the VC120 was designed, installers and users commented that current volume controls designs (all transformer types) had too many volume settings primarily on the lower settings and that each "click" didn't affect the sound level enough. In Transformer-Free™ designs, eliminating some lower settings allows for more room to increase the overall power rating and reduced size (see note 4). The Knoll VC120 has a peak power rating of 400 watts for five seconds (presently the highest in the business) with six very usable volume control settings including fully off. The VCS95 has a peak power rating of 350 watts and 11 positions including fully off.

6.3 Best Sound Quality

When splitting and controlling speaker level signals, it is best that the signal itself not be altered, only split or level controlled with regards to amplitude. Why would someone want to spend a great deal of money on a large multi-room stereo system only to have the sound quality compromised by a poor sound quality stereo volume control or splitter? Transformers always cause linearity problems, which are acoustically evident and therefore are usually the weakest "link" in the custom installation or multi-room stereo "chain". Transformer-Free™ designs do not alter the signal content, only the level, giving them the best sound quality.

Note 1: Knoll SI and WM series transformer free STEREO INTERFACES safely allow three to six or more pairs of stereo speakers to be connected in parallel without causing amplifier damage or shut down from low impedances.

Note 2: All models of Knoll transformer free volume controls (except POWERMATCH) directly connect the amplifier to the speaker in the fully on (clockwise) position allowing a damping factor equal to a system without volume controls.

Note 3: Speaker level splitters such as the Knoll SI1x6 Stereo Interface (one stereo to six speaker zones, 300 watts RMS per channel) require large-scale ventilation with high temperature ratings on all internal components so the interfaces do not exceed their maximum rated temperature. Stereo volume controls are normally mounted in-wall. Knoll transformer- free stereo volume controls have special ceramic elements that store heat with slow release times eliminating temperature spikes that can create a fire hazard. This is why the Knoll VC120 stereo volume control has a 400 watt power rating for five seconds and is the nature of the patent pending on Knoll stereo volume controls and stereo interfaces.

Note 4: The special ability of ceramic tile heat storage with slow thermal dissipation is the basis of the patent pending on Knoll Transformer-Free™ volume controls and stereo interfaces.