Input and Output Circuits for THAT Preamplifier ICs

Phantom Power, Mic-Input Pads, Line Inputs, Single-ended and Differential Outputs

Microphone preamplifier designs must satisfy many challenging requirements. These include low noise performance with low source impedances, high signal-handling capability, high radio-frequency (RF) immunity, high common-mode signal rejection, and variable differential gain over a range of 1 to 1,000 (or more). Mic preamps are often required to serve "double duty" as line input stages. And, professional mic preamps must supply a source of phantom power, usually +48V, to the microphone. The presence of phantom power mandates protection networks, which tend to conflict with some of the above design goals.

This design note describes practical input and output circuits for THAT microphone preamplifier ICs which satisfy the above requirements. While the circuits illustrated herein utilize the THAT 1570 preamplifier, many of the circuits are applicable to other THAT preamp ICs, including the 1510 and 1512. This note stops short of providing detailed circuitry for controlling switchable functions using electronic control such as the general purpose outputs ("GPOs") provided by THAT's 5171 preamplifier controller IC. In fact, all the switching shown herein assumes mechanical switches, either manually activated or controlled via relays. Look for a forthcoming design note to cover electronic switching and control in detail.

Basic Microphone Input Circuit with Phantom and Pad Switching

When a preamplifier must be configured to accept mic-level inputs only, we recommend the circuit shown in Figure 1. This circuit offers switchable phantom power, a 20 dB input pad (optional -- not required in many situations), and protection against phantom power faults (the "Phantom Menace," see references 1 and 2). It maintains excellent noise performance, and is relatively immune to RF interference. Note that common-mode rejection is provided by a subsequent stage; so long as R1 and R2, and R8 and R9 are well matched, the design will not convert common-mode input signals to differential ones, which would spoil the ultimate common mode rejection provided by subsequent stages. Gain, controlled by varying R_G, may be varied from nearly 0dB to over 60dB.

Phantom Power Switching

R1 and R2 provide phantom power to the mic. Because thick-film resistors often produce excess noise, these resistors should be high-quality, thin-film types to ensure that their noise contribution is minimal. Note that with a shorted input and +48V phantom active (SW1 in the "ON" position), each resistor will dissipate 0.338W. A 1/2W through-hole or (at least) 1/3W surface-mount resistor is required if these parts are to survive shorted inputs with phantom switched on. Their tolerance should be 1% or better in order to avoid converting common-mode signals to differential.

Switch SW1 is used to switch phantom power on and off. There are three phantom power switch types: A, B, and C. (See Figures 1, 2, and 3.) They differ in how they discharge C1 and C2 when phantom power is switched off.

Generally, we recommend type A. This circuit maintains the same AC load on the input pins regardless of whether phantom is switched on or off. (We neglect the period when the switch is open when being moved between the poles. Of course, a shorting switch — also
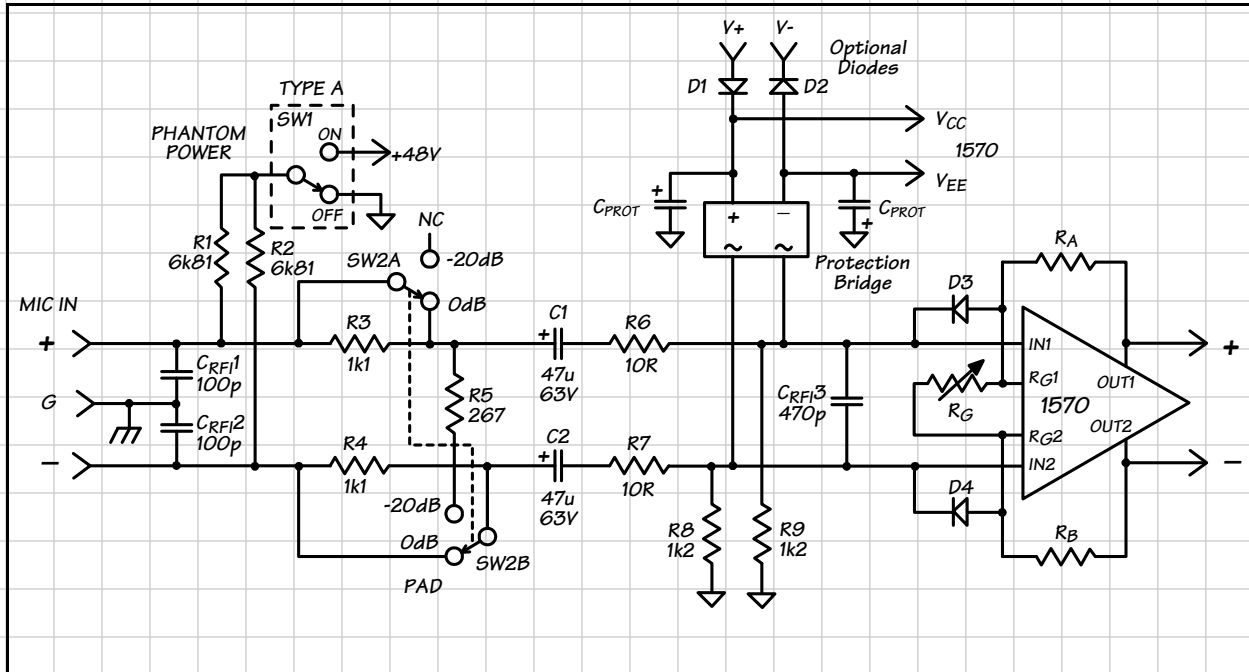
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Figure 1. Preamp including phantom power and protection, a mic-input pad, and RFI protection.

known as "make before break" — would be inappropriate here.) In certain line input attenuator circuits, described later, type A is required to maintain attenuator accuracy.

In the type A variation, when phantom is switched off, R1 and R2 discharge C1 and C2 through S1 relatively quickly. With the 47μF coupling capacitors shown, the discharge time constant is about 320ms.
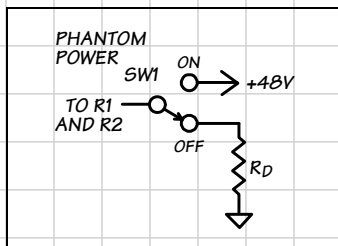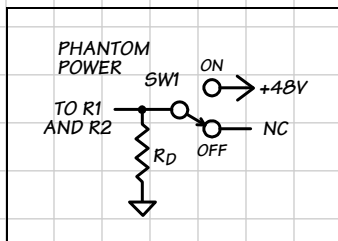

Figure 2. Alternate "B" phantom power switching.

Figure 3. Alternate "C" phantom power switching.

When two mic inputs are connected together ("multed" or "bridged" to provide a "split"), only one preamp's phantom power should be turned on. The disadvantage of Type A is that when two such preamps are multed, the phantom power voltage is cut in half due to the dc load presented by R1 and R2 in the preamp whose phantom is off. Therefore, if a "mult" connection is expected, we recommend the circuits of types B and C.

Type B and C phantom switching discharges the input coupling capacitors through a single common resistor R_D. When phantom is off, the DC load on the inputs is increased by R_D. To minimize this loading, R_D is generally much larger than the 6.81 kΩ phantom source resistors. Of course, this lengthens the discharge time constant as well.

Type B avoids wasting power in R_D since it is out of the circuit when phantom power is turned on. Type C has the advantage of using a SPST switch[1], but R_D dissipates power whenever phantom is turned on. This might be significant when phantom power is derived from limited power and/or voltage sources such as batteries or USB bus power.

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[1] When using mechanical switches or relays, there is likely no advantage to an SPST switch over a SPDT type. However, when switching phantom electronically, this can be important.

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Some microphone preamplifier designs include an RC network to slowly ramp up the phantom voltage when it is turned on. This is essential when the common-mode voltage applied to the active device's inputs must be limited. However, such a network is not required in the circuit of Figure 1, because the peak input voltage (at the 1570) when phantom is turned on is limited by the voltage divider formed by bias resistors R8 and R9 along with R1 and R2. With the values shown, the peak voltage is approximately +7V. (Of course, a 7V dc offset, even if mostly common-mode, can make a significant thump in subsequent circuitry if the preamp gain is high when phantom is turned on!)

Mic-Input Pad

When operating from ±15V supplies, THAT's 1570 preamplifier accepts up to +26.8dBu differential input signals at minimum (unity) gain, without clipping its input or output. (When used with the 5171 companion digital control part, the maximum input signal is +21dBu due to the 5171's minimum gain of 5.6dB. And, of course, when run from higher supplies -- ±18V for the 1570, and ±17V for the 5171 -- the pair can accept higher signal levels.) THAT's 1512, which includes an internal -6dB gain differential-to-single-ended amplifier, accepts up to +27.5dBu input at its minimum gain (-6dB). THAT's 1510, which includes an internal unity gain differential amplifier, is limited to +21.5dBu input at minimum gain. A mic-input pad allows the preamplifier to accommodate higher input signals (as may be produced by "hot" mics and close-miked instruments), and if designed properly, increases headroom with little sacrifice to noise and dynamic range.

Switch SW2 (A and B sections, Figure 1) along with R3, R4, and R5 form a balanced differential "U-pad" with 20dB attenuation. The U-pad topology reduces the tendency for resistor matching errors between R3 and R4 to degrade common mode performance. R3, R4, and R5 combine with R1, R2, R8, and R9 to present a nearly constant impedance (2KΩ) load to the microphone regardless of whether the pad is switched in or out. (We neglect C1, C2, R6, and R7 for this analysis.) When SW2 is in the "0dB" position, a microphone "sees" (as a differential load) the series combination of R1 and R2, in parallel with the series combination of R8 and R9. With the values shown, this is approximately 2kΩ. When SW2 is in the -20dB position, a mic sees the series combination of R1 and R2, in parallel with R3 and R4 in series with the parallel combination of R5 and the series combination of R8 and R9. This is also approximately 2kΩ.

Another desirable attribute of this circuit is that when the pad is switched in, the active element (1570) "sees" a very low source impedance when "looking outward" into the pad. (This is less than 240Ω, even with an open circuit at the input.) For amplifiers optimized for low noise with low source impedances (such as the 1570, 1510, and 1512), this low source impedance maintains excellent noise performance.

The mic-input pad's attenuation may be varied to suit system requirements. Table 1 offers different recommendations for the values of R3, R4, and R5 to accommodate different maximum input signal levels. All these attenuators maintain the preamp's differential input impedance at about 2kΩ.

Note that because the bias resistors (R8 and R9) form a part of the attenuator, if their values are changed from the 1.2kΩ shown, the attenuator values must be changed as well.

Attenuation (dB)	R3, R4 (Ω)	R5 (Ω)	Maximum Input (dBu) @ 0dB 1570 gain
20	1,100	267	46.8
15	976	511	41.8
10	806	1,070	36.8

Table 1. Resistor values for alternate mic-input pad attenuation, circuit of Figure 1, assuming ±15V supplies.

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Phantom Power Protection

Phantom power protection is essential to ensure that the preamplifier will not be damaged by phantom power faults. Phantom power faults take many forms. The most common potentially damaging fault is a short to ground from one of the system inputs (positive or negative) when the input coupling capacitors are fully charged. Under normal operation, when phantom is switched on and no mic is connected, C1 and C2 charge to 48V, positive towards the microphone input. If either input is connected to ground, the opposite side of the input coupling capacitor applies -48V to the IC input, because the voltage across a capacitor cannot change instantaneously. Most active devices, typically powered from ±12V to ±18V, cannot withstand such high input voltages. Unless adequate precautions are taken, the resulting current can destroy the active device.

Figure 1 includes resistors R6 and R7 to limit peak currents during phantom faults, a diode bridge to clamp the IC's input voltage to the regulated supply rails, capacitors C_{PROT} to absorb charge from C1 and C2, and diodes D3 and D4 to route fault currents outside the chip. In practice, we have found that the supply rails do not actually clamp, but instead the rails move with the voltage on C1 and C2. (Larger C_{PROT} will reduce this tendency.) This prevents excessive currents from flowing in the IC preamp, and the momentary over-voltage, while beyond the device's maximum ratings, generally does not cause harm to THAT's preamplifier ICs. The optional diodes D1 and D2 serve to isolate the preamp power supply from that of other circuitry. They may be necessary if other devices (particularly active ones) do not fare so well with -48V applied to their negative supply pins.

More information on phantom power protection schemes can be found in individual THAT preamplifier data sheets. Please also refer to "The 48V Phantom Menace Returns" (reference 1) and its predecessor "The 48V Phantom Menace" (reference 2).

R6 and R7 require special consideration because they see very high peak currents during phantom power faults. Currents in excess of 3A are not uncommon. For through-hole construction, conventional 1/4-W metal-film resistors will suffice. For SMT applications, these resistors must be specified to handle high peak currents (see reference 3). Designer Steve Dove has suggested using a common-mode choke (primarily as part of an RFI network) which happens to have about 10Ω resistance per leg. This idea seems worth exploring.

Radio-Frequency Interference (RFI)

RFI protection is important because high-gain preamplifiers can rectify radio frequencies, causing audible interference. Figure 1 includes a pair of RF bypass capacitors $C_{RFI}1$ and $C_{RFI}2$ which shunt the input connector pins to chassis ground. Their purpose is to stop RF from entering the preamplifier enclosure. These capacitors should be located as close as possible to the input connector, and should return to the input connector's shield with as short a path as possible. These capacitors are effective against both differential and common-mode RFI.

Figure 1 also includes $C_{RFI}3$, which further reduces incoming differential RFI, as well as any differential RFI generated within the preamplifier enclosure (e.g., from clocks, switching power supplies, and other digital signals). More details about RFI protection can be found in the individual THAT preamplifier data sheets.

Accommodating Line Inputs

Mic/Line Input with Variable Gain

In many circumstances, gain of a line-level input must be varied by the same mechanism used to control microphone gain. Accordingly, the line-level signal must be sent through the mic preamp. Generally, line inputs must accept higher levels than microphone inputs. And

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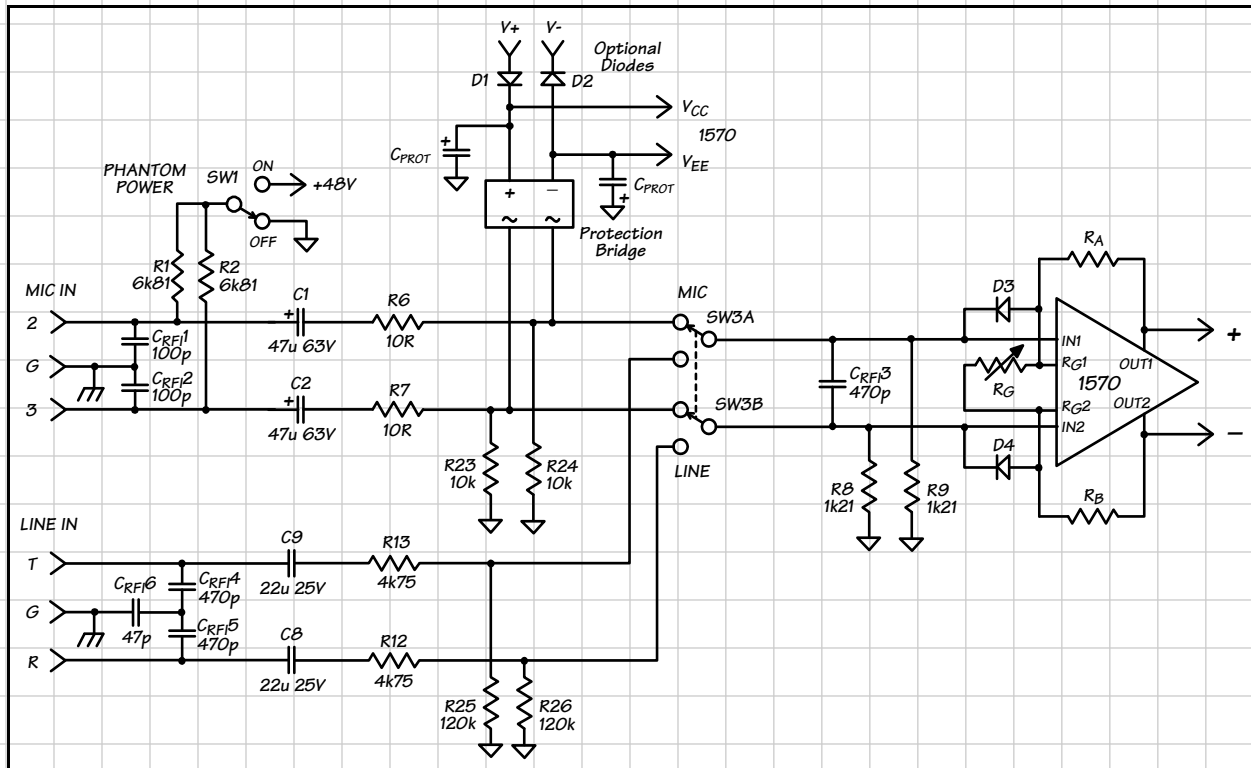45 Sumner St; Milford, MA 01757 USA; www.thatcorp.com; info@thatcorp.com

Figure 4. Basic mic/line switching supporting variable gain at both inputs.

importantly, they usually present a higher input impedance to the outside world. Maintaining good noise performance in this configuration is not straightforward, and, like most design work, involves tradeoffs.

A line-input pad is often used to accomplish the dual purposes of raising the input impedance and maintaining a low source impedance for the active gain stage. This latter is important because bipolar input stages like those used in THAT mic preamp ICs are generally run at high collector currents. This results in significant input current noise, which can swamp the IC's extremely low voltage noise if allowed to flow through a high impedance. Accordingly, we recommend that THAT mic preamp ICs "see" a differential source impedance of no higher than about 2kΩ.

Figure 4 shows an example of a line-input pad added to the circuit of Figure 1, via resistors R12 and R13, working against R8 and R9. (For clarity, the mic-input pad is not shown, but it could be added as well.) DPDT switch SW3 selects between the mic and the line input. Note that SW3 also isolates the phantom power system from the line input connector in case of a phantom power fault.

R23 and R24 are required to provide a discharge path for C1 and C2 when the mic/line switch is in the line position. Their value, shown at 10k, is not critical. It should be large enough not to add significantly to the loading of the microphone (or C1 and C2) in mic-input mode, but small enough to minimize the discharge time.

With the values shown, at unity line-input system gain (+13.9dB in the 1570: $R_A=R_B=2.21k\Omega$, $R_G=1.10k\Omega$), the input-referred noise floor of the line input is -102.3dBu, and the maximum input signal is at least +26.6dBu. At minimum system gain (0dB in the 1570) the input-referred noise floor is -94.7dBu, and the maximum input signal is over +40Bu.

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Higher input impedance can be achieved by setting the line-input pad's attenuation to a higher value, but more attenuation inevitably compromises noise. In most cases, where the goal is to maintain the widest dynamic range, we believe that the required minimum input impedance will more likely define the optimum attenuator design than will the required attenuation. (Note that in the circuit of Figure 4, when the 1570 is set for 0dB gain, no attenuation is required to accept up to nearly +27dBu. Thus, only a little more than 3dB attenuation is required to handle a +30dBu input signal.)

Line input impedance represents a tradeoff between noise floor (lower impedances lower the noise) and common-mode rejection (higher impedances preserve common-mode rejection when the differential sources have slightly different – low – output impedances). The optimum choice of input impedance will depend on skillfully trading off these two conflicting design goals.

Generally, we recommend that the attenuator be determined based on the minimum required input impedance. Calculate an attenuator R12/R8 (and R13/R9) to generate that input impedance, based on R8=R9=1.21kΩ. Check that this attenuation offers enough headroom to satisfy design requirements. (Headroom at the line input increases with the amount of attenuation.)

If more headroom is required, then more attentuation is needed. In this case, to maximize dynamic range, we recommend using the additional flexibility provided by R25 and R26 to increase attenuation without raising the input impedance above the target value. To do this, increase the values of R12 and R13 while decreasing R25 and R26. This approach will lower the system noise over merely increasing R12 and R13 to increase attenuation.

In some cases, designers may be focused on achieving a specific attenuation. In such cases, better noise performance and, thus, wider dynamic range, can sometimes be had by lowering the values of R25 and R26 rather than raising the values of R12 and R13. R25 and R26 offer an additional degree of freedom by lowering the attenuator's termination impedance below 1.21kΩ (the values of R8 and R9). In some situations, this can lower the system's noise floor, though at the expense of input impedance.

The major advantage of the topology of Figure 4 is that gain for both mic and line modes is varied by varying R_G, or R_G, R_A, and R_B simultaneously. (For THAT1510 and 1512, only R_G may be varied.) One disadvantage is that the line-input sensitivity is lower than the mic-input sensitivity, and for equivalent gain, the line-input noise performance will not be quite as good as that from the mic input. Dynamic range increases as system gain is lowered, but the increase consists exclusively of additional headroom. Unless it is important to accept input signals exceeding 30dBu, the headroom may not be of much use.

Table 2 shows a few options for the line-input attenuator, starting with the common-mode input impedance, and assuming that R25 and R26 remain high values. This table assumes that the system gain is -6dB, determined by the combination of the R12/R8 (or R13/R9) attenuator, along with the 1570 gain (set by R_G as listed).

Despite the significant (~20dB) attenuation in the 24.4kΩ (differential) input impedance case in Table 2, because of the 1570's excellent low-gain noise performance, line input dynamic range is close to that available from a conventional (single opamp) differential line input with Z_{IN}=24kΩ (differential). For example, THAT 1246, which offers 24kΩ Z_{IN} and (fixed) -6dB gain, accommodates +27.5dBu maximum input signal, has input referred noise of -100dBu, and a dynamic range of 127.5dB. But, the lower impedance variations in Table 2 clearly offer more dynamic range, with the lowest offering the lowest noise.

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Line Input Impedance (Ω)		R12, R13 (Ω)	Pad Attenuation (dB)	IC Gain (dB)	R_G for -6dB system gain (Ω)	Max Input Signal (dBu)	Input Referred Noise (dBu)	Dynamic Range (dB)
Common-Mode	Differential							
12.2k	24.4k	10.7k	20	14	1,100	32.6	-95.6	128.2
6k	12k	4.75k	13.9	7.9	3,010	32.6	-99.8	132.4
$3k^2$	$6k^2$	1.82k	8	2	16,900	32.6	-102.3	134.9

Table 2. Variations on the circuit of Figure 4 alter Z_{IN} and dynamic range. Values shown result in a line-input system gain of -6dB.

Another limitation to line-input performance with the approach of Figure 4 is that the common-mode performance of the line input will be partly determined by the match between the ratio of R8/R12 and that of R9/R13. Designers might be tempted to use a "U-pad" or balanced attenuator (similar to R3/R4/R5 in Figure 1) in which the center of the attenuator remains floating. We advise caution with this approach because line input sources are not consistently balanced. The attenuation of a U-pad changes when the source switches from balanced to unbalanced. The two "L-pad" attenuators shown in Figure 4 (R8/R12 and R9/R13, with each attenuator tied to ground) maintain constant attentuation regardless of whether the source is balanced or unbalanced, and whether the TRS connection used is Tip-Ring or Tip-Ring-Sleeve.

DC blocking capacitors and clicking

Switching inputs in front of the preamplifier is problematic. In practice, we find that it is impossible to avoid clicks with affordable circuitry.

As usual when using phantom power, capacitors C1 and C2 isolate the mic input side of SW3 from dc variations. Capacitors C8 and C9 serve the same purpose for the line input side. (They are rated for lower voltage because they are less likely to be exposed to phantom power.) It is customary when switching audio signals to include dc-blocking capacitors in series with the wipers of the switch (SW3). Theoretically, an additional pair of capacitors is required to provide click-free performance. Such additional capacitors would serve to prevent the 1570's input bias current from being drawn through different paths before, during, and after SW3 is thrown.

But, in the circuit of Figure 4, we have found that additional capacitors are of little help. Other sources of dc offset are much more significant than the input bias current of the 1570. This circuit generally produces clicks even if the wipers are isloated via capacitors.

To understand why this is so, consider the following. When SW3 is moved, the two poles will not open and close at identical times. Thus, any common-mode dc differences between the mic-input and line-input poles of SW3 will be converted to differential (and thus made audible) when the switch is moved. And, with the potential for over 60dB gain in the preamp following the switch, even 1μV of dc error before the switch can create a 1mV or ~ -60dBu dc shift at the preamp's output. Therefore, to eliminate audible clicks, all dc offsets (differential or common-mode) before the preamp must be kept under 1μV or so.

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[2] Reducing the differential input impedance to 6kΩ (3kΩ common-mode input impedance) lowers noise and increases dynamic range, but may well be too low for many professional audio applications. Use caution with such an approach.

While it may be reasonable to assume that the voltage across R25 and R26 will be very close to zero, this is not the case for the voltage across R23 and R24. When phantom power is turned on via SW1, C1 and C2 charge to +48V (somewhat less when a microphone which draws current through R1 and R2 is connected). If C1 and C2 are ideal capacitors, the voltage across R23 and R24 will settle to 1μV within about 18 time constants, or about 9 seconds for the values shown. But, C1 and C2 are typically electrolytic types which have non-trivial leakage current at 48V[3]. Any leakage will flow through R23 and R24: even 100nA will create 1mV of dc offset. At 60dB gain, this results in a 1V output click when SW3 is switched!

Another factor is dielectric absorption. This phenomenon, also called "soakage", results in extremely long time constants to fully discharge the electrolytic capacitors typically used for C1 and C2 – many orders of magnitude larger than that which the simple RC formula would predict[4]. Assuming phantom power has once been turned on, dielectric absorption impacts the circuit's behavior when phantom power is off for a very long time. In one experiment, after being charged to 48V for a few minutes, we turned off all power for over one hour. Coming back to the circuit on the bench, with power still off, we measured voltage across C1 and C2 on the order of 10mV. (One measured about 7mV, the other about 14mV.) We then shorted out both capacitors for a few seconds. After removing the short, we saw the voltage across both caps rise over many seconds to nearly the same value as before shorting out the capacitor.

Of course, clicking becomes less audible at low gains. Accordingly, one method to reduce clicking is to ensure that the preamplifier gain is set to minimum when the mic/line switch is moved. With electronic gain control via THAT5171, this can be easily accomplished. For mechanical switches, a third contact could momentarily open Rg. (If additional contacts are available - not shown - one of them could also be used to modify the active element's gain range for line inputs.)

Line Inputs and Electronic Gain Control Using THAT1570 and 5171

When THAT1570 is used with a 5171 digital gain controller IC (Figure 5), the gain steps in the 5171 should be considered when designing a line-input attenuator. As with the circuit of Figure 4, assuming the maximum recommended input bias resistance (R8 and R9) of 1.2kΩ, the attenuator will determine the line-input impedance, noise floor, and dynamic range.

The 5171 provides a minimum gain of 5.6dB, plus a series of gains from +13.6 to +68.6dB in 1dB steps. When used as a line-input amplifier, this gain range suggests at least two likely choices for the line-input attenuator. Perhaps the most likely configuration, shown in Figure 5, is to set the attenuator to -13.6dB. This yields a differential Z_{IN} of 11.4kΩ (common-mode Z_{IN} of 5.7kΩ), and a range of system gains from 0dB to 56dB in 1dB steps, plus a -8dB gain step.

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[3]"Low leakage" electrolytic capacitors seem mostly to be specified for leakage as 0.002CV, where C is the capacitance and V is their working voltage. See references 8 and 9. For a 47μf, 63V capacitor, that amounts to almost 6μA of leakage, which creates over 7mV of offset with SW3 in the mic position. Even if the capacitor performs ten times better than its limit spec, the resulting offset would be the better part of 1mV. Moreover, leakage increases with temperature.

[4]See reference 10 for more details.

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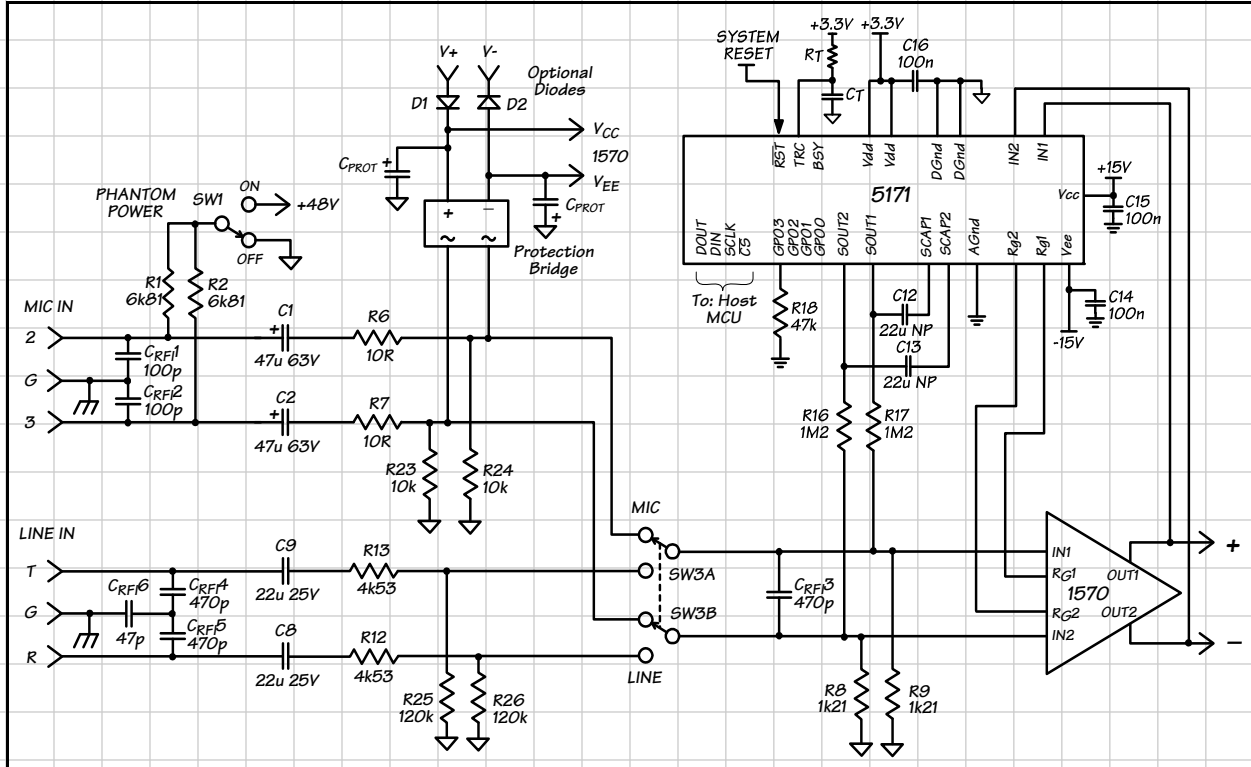45 Sumner St; Milford, MA 01757 USA; www.thatcorp.com; info@thatcorp.com

Figure 5. Mic/line switching while using a 5171 to control preamp gain.

Another likely configuration, with lower input-referred noise, would be to set the attenuator to -8dB. This yields differential Z_{IN} of 6kΩ, and a range of system gains from 5.6dB to 60.6dB in 1dB steps, plus a -2.4dB gain step.

Table 3 below shows the performance of these two configurations. Of course, other attenuators may be designed to suit specific performance objectives.

Line Input Impedance (Ω)		R12, R13 (Ω)	Pad Attenuation (dB)	5171 Gain Setting	Line-In System Gain (dB)	Max Input Signal (dBu)	Input Referred Noise (dBu)	Dynamic Range (dB)
Common-Mode	Differ-ential							
5.7k	11.4k	4.53k	13.6	"8"	0	26.6	-101.2	128.8
5.7k	11.4k	4.53k	13.6	"0"	-8	34.6	-95.6	130.2
$3k^2$	$6k^2$	1.82k	8	"8"	5.6	21	-107.3	128.3
$3k^2$	$6k^2$	1.82k	8	"0"	-2.4	29	-101.4	130.4

Table 3. Variations on the circuit of Figure 5 alter Z_{IN} and dynamic range. Values shown result in a system gain of -6dB.

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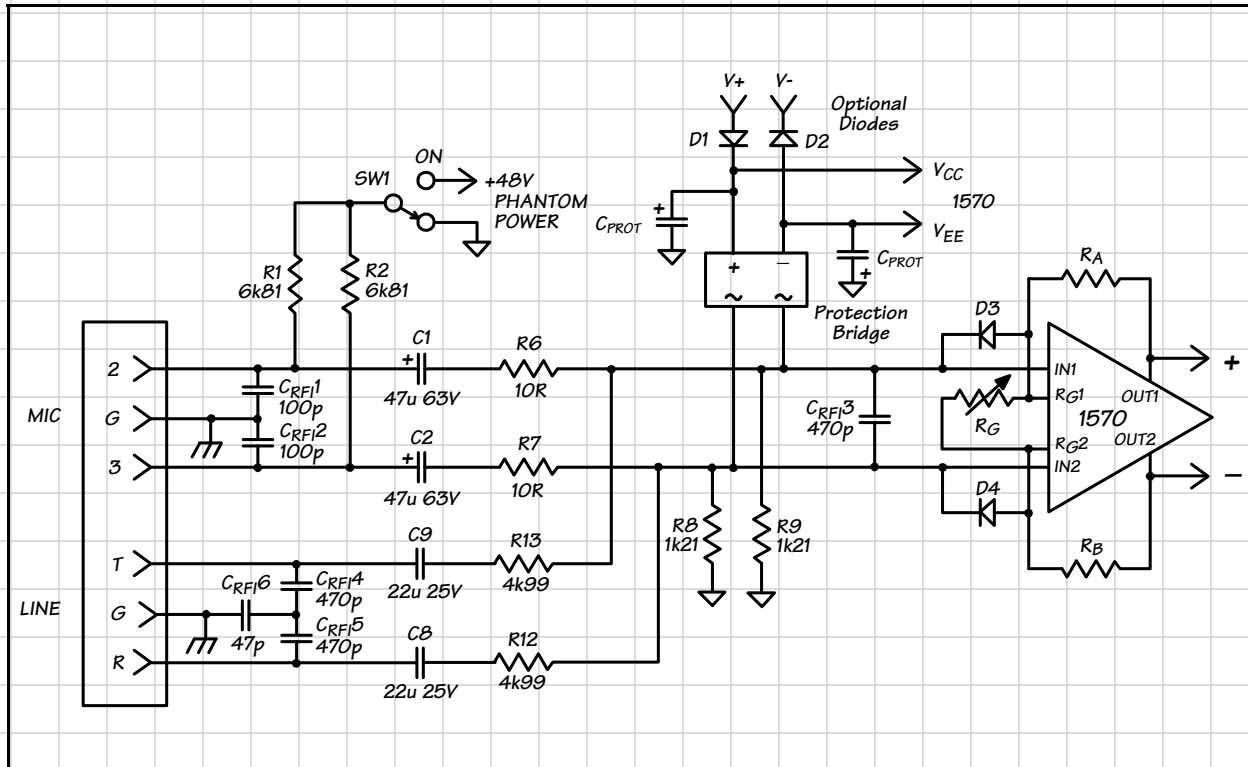45 Sumner St; Milford, MA 01757 USA; www.thatcorp.com; info@thatcorp.com

Figure 6. Using "combo" connectors for mic/line switching.

Simple Mic/Line Inputs Using "Combo" Connectors

If a combo-style connector which combines XLR mic and TRS line inputs in a single device is used, it will be physically impossible for both inputs to be used simultaneously. In such cases, switch SW3 can be omitted. Figure 6 shows a suitable circuit. Depending on design objectives, C8 and C9 might be eliminated, leaving the line inputs DC coupled through to the line-input attenuator.

It is possible to use this circuit with separate XLR and TRS connectors as well. In such applications, the operator determines mic or line inputs via choice of the connector to be used. Of course, both connectors should not be used simultaneously.

In Figure 6, R12 and R13 provide the same 12k (differential) input impedance as in Figure 4, but their values are higher because R8 and R9 are paralleled, respectively, by R2 and R1. (C1 and R6 along with C2 and R7 are in series with the phantom power resistors, but their effect is minimal, so they can be ignored for sake of this discussion.) This yields a slightly larger attenuation (-15.4 dB) but maintains the ~12kΩ input impedance. As shown in figure 6, the attenuator is made up of R12 against R8||R2, and R13 against R9||R1, or 4.99kΩ against ~1.03kΩ (1k21Ω||6.81kΩ =1.03kΩ).

Of course, other line-input attenuation values may be used. Generally speaking, the less attenuation used, the lower the line-input impedance and the larger the dynamic range of the line input, and vice-versa. Table 4 shows a set of alternatives for the circuit of Figure 6, similarly as Table 2 does for Figure 4.

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Line Input Impedance (Ω)		R12, R13 (Ω)	Pad Attenuation (dB)	IC Gain (dB)	R_G for -6dB system gain (Ω)	Max Input Signal (dBu)	Input Referred Noise (dBu)	Dynamic Range (dB)
Common-Mode	Differential							
12.1k	24.2k	11.1k	21.4	15.4	909	32.6	-95.2	127.8
6k	12k	4.99k	15.4	9.4	2,260	32.6	-99.4	132
$3k^2$	$6k^2$	2.00k	9.4	3.4	9,310	32.6	-102	134.6

Table 4. Variations on the circuit of Figure 6 alter Z_{IN} and dynamic range. Values shown result in a line-input system gain of -6dB.

To maintain accuracy of the attenuation regardless of the position of the phantom power switch, a Type A phantom switch should be used. This keeps R1 and R2 at AC ground in both switch positions.

Like the circuit of Figure 4, the circuit of Figure 6 has the advantage of allowing mic- and line-input gain to be varied by the gain of the IC preamplifier. It has the disadvantage that common-mode performance depends on resistor ratio matching.

Fixed Line-Input Gain

In some applications, the line inputs for a product have fixed, not variable gain. If this is the case, the best approach to the line input stage is usually to provide a line input section separate from the mic preamp. In such cases, the switch would naturally follow the (variable gain) mic preamp. Especially when using THAT 1570 as the mic preamp, it is possible to take advantage of this arrangement to use the line input's common-mode rejection to benefit the mic input as well.

The common-mode gain of instrumentation amplifiers like THAT 1570 is always unity. Thus, the common-mode rejection ratio is equal to the differential gain. To maintain good common mode rejection in the preamplifier at all gains, common-mode signals must be rejected in a separate stage. When the ultimate goal is a single-ended output, this is usually performed by a simple differential-to-single-ended converter: the ubiquitous differential amplifier[5].

To illustrate the concepts involved, we will first assume that the mic and line signals must be converted from differential to single-ended signals. The right differential-to-single-ended converter can also provide a very high performance line input. (A variation of this technique is applicable when the goal is to create a differential output with common-mode components removed. We discuss differential outputs in the following section.)

THAT 1246 is a high-performance line receiver intended to be used directly as an audio line receiver. It is typically configured for a gain of -6dB. Figure 7 shows a 1246 switched via SW3 between the output of THAT1570 and an input connector to provide a fixed gain, high performance line input.

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[5]THAT 1510 and 1512 IC preamps include a good-performance differential amplifier within the parts. Their common-mode rejection is the sum of the differential gain plus the common-mode rejection of the internal differential amplifier (the latter is typically ~50dB). In contrast, THAT 1570 has a differential output suitable for driving low-impedance R_A and R_B; to maintain common-mode rejection at low gains, the designer must add an external differential amplifier.

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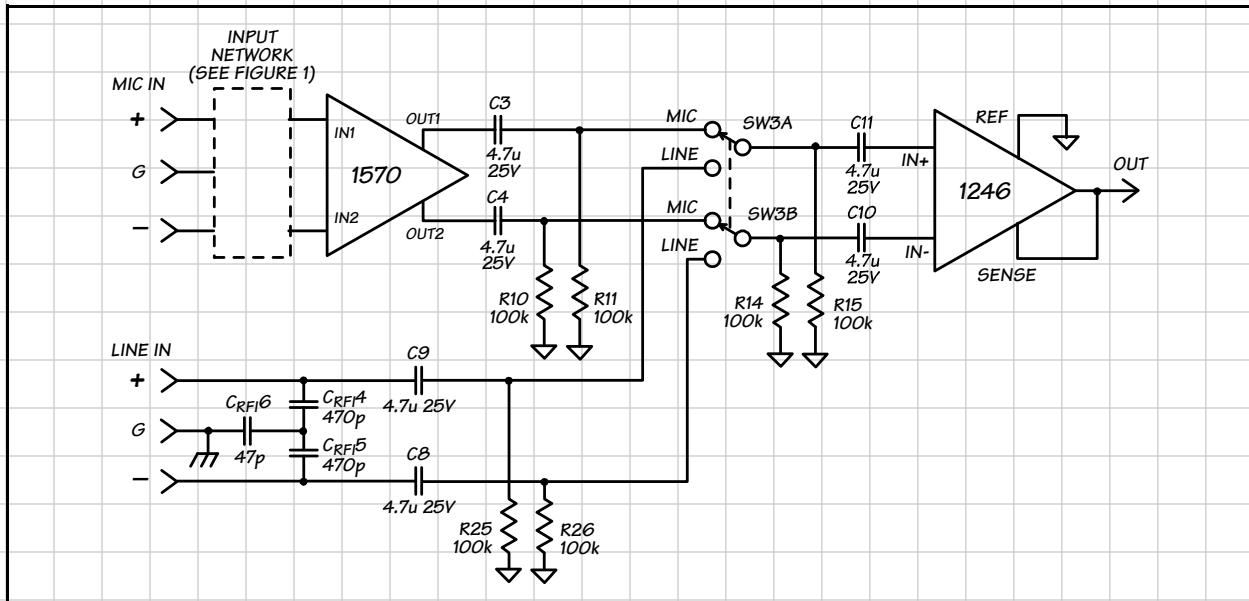45 Sumner St; Milford, MA 01757 USA; www.thatcorp.com; info@thatcorp.com

Figure 7. Fixed-gain line input using high-CMR differential amplifier.

The two 1570 outputs sit at the same quiescent DC potential of one Vbe below ground (~ -0.6V). Ordinarily, AC-coupling between the 1570 and an output differential amplifier (like the 1246) is not required because the common mode rejection of the line receiver eliminates the DC offset. However, when the output is switched as shown in Figure 7, AC coupling is required to eliminate clicking. AC coupling, by means of C3, C4, R10, and R11 block this DC offset, helping to ensure silent switching. These capacitors are smaller[6] than those shown in previous figures since the load offered by the 1246, at 24kΩ (differential), is higher than that offered by the line-input attenuators shown in the previous circuits. C8/C9, and discharge resistors R25 and R26 block any DC potential on the line input. Finally, C10/C11, and R14/R15, ensure that the 1246 input bias currents are not forced to flow through different source impedances when SW3 is moved.

An additional switch can be placed into the differential signal path to provide polarity inversion for both line and mic inputs. Figure 12 shows an example.

1570 Output Stages

As mentioned earlier, the THAT 1570 has unity common-mode gain, regardless of its differential gain setting. Common mode signals are passed directly from the differential input to the differential output. Typically, a differential to single-ended converter removes the common-mode signal. THAT's 1246 and (dual) 1286 differential amplifiers provide typically 90dB common-mode rejection (CMR). For less demanding applications, THAT's 1256 and (dual) 1296 provide typically 50dB CMR at lower cost.

Figures 8-11 provide examples of circuits to generate either single-ended or balanced outputs. All the output stages shown below remove the DC common mode component at the 1570 preamplifier output. They do this when DC coupled to the 1570 outputs; AC coupling capacitors C3 and C4 in Figure 7 are only necessary when switching the output of the 1570. As well, the balanced output circuits of Figures 10 and 11 provide a node at which to inject the common-mode offset required for A/D conversion.

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[6] An argument for choosing even larger capacitors comes from the fact that, at 4.7uf, these capacitors are likely to be electrolytic types, which tend to have high tolerances and lose capacitance as they age. Poor matching of these capacitors will reduce common-mode rejection at low frequencies. For a given mismatch, larger capacitors will have less initial impact on CMR, and will suffer less as they age.

Unbalanced (Single-Ended) Outputs

Figure 8 shows the simplest way to obtain an unbalanced (single-ended) output. A THAT 1246 or 1256 (single) or one-half of a 1286 or 1296 (dual) line receiver, configured for -6dB gain, performs differential-to-single-ended conversion. The laser-trimmed resistors inside the 1246/1286, provide very high -- typically 90dB -- common mode rejection; the untrimmed 1256/1296 offers typically 50dB. This perform-ance is generally better that of than circuits using individual external resistors (e.g. Figure 9).
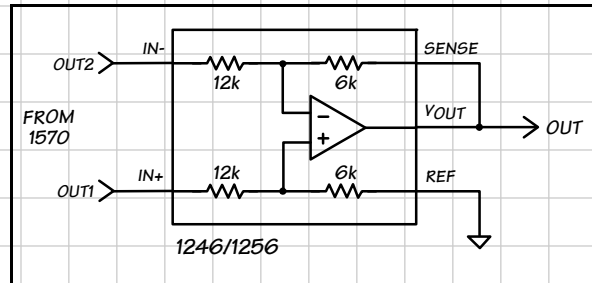
Figure 8. Simple single-ended output.

Since the 1246/1256 was originally designed to serve as a line input stage, its input impedance as a -6dB line input (~24kΩ) is appropriate for line receiver applications. However, this impedance compromises noise by about 8dB compared to the noise at the output of a unity-gain configured 1570 ($R_A = R_B = 2.2k\Omega$, and open R_G). Note that this compromise affects only low gains. For example, at 5.6dB gain -- the minimum gain when the 1570 is used with a 5171 -- the compromise is about 4dB; for gains above about 30dB, its impact is negligible.

When very low noise at low gains is required, low-value resistors and a quiet opamp provides the ultimate noise performance in differential-to-single-ended conversion. The circuit of Figure 9 uses discrete resistors and a low voltage-noise opamp, such as an NE5534, NE5532 (dual), or NJM2114 (dual) to minimize noise. The 2114 in Figure 9 adds about 2.5dB to the 1570 noise floor at unity gain; the 2114's added noise is negligible for gains above about 7.5dB. Another advantage of this approach is that the designer has flexi-bility in choice of gain. When the 1570 preamplifier is paired with a 5171 preamp controller, the preamp's minimum differential gain is +5.6dB. Accordingly, the circuit in figure 9 is configured for precisely -5.6 dB attenuation, yielding a minimum 0dB system gain.

Note, however, that due to the low input impedance of this circuit (differential Zin = 4.3KΩ, common-mode Z_{IN} = 2.15 kΩ per input pin), we do not recommend it for use as a switched line input as shown in Figure 7. As well, common-mode rejection of the circuit of Figure 9 is limited by resistor matching. With 1% resistors, the worst-case CMR can be as low as 31.5dB, with 0.1% resistors, this improves to 51.5dB. To match the laser-trimmed 1246/1286 performance in CMR, matching must be within at least 0.01%; to match the un-trimmed 1256/1296 performance, matching must be within 0.4%.
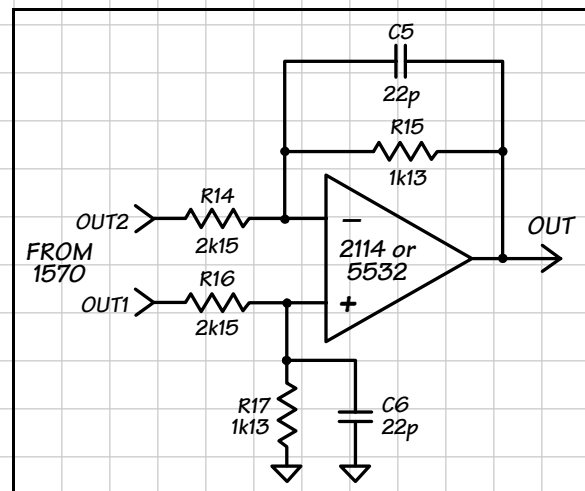
Figure 9. Quieter single-ended output circuit.

Balanced Outputs

Figure 10 uses a straightforward "double balanced" configuration to realize common mode rejection without converting to a single-ended output. (Similar circuits have been suggested by others, see reference 4.) Each differential amplifier acts independently of the other, but their inputs are cross-connected so their outputs appear in opposing polarity.

Gain from input to output is 0dB; each stage has -6dB gain, when differenced at the output the opposite-polarity signals add 6dB of signal level.

Because each differential amp provides good (excellent, in the case of the laser-trimmed 1286) common-mode rejection, the entire circuit provides good to excellent CMR performance. With the 1286 (or two 1246 ICs), CMR is typically 90dB. For less critical applications a pair of THAT 1256 ICs or one (dual) 1296 can be used.

One subtle difference between the 1246/1256 and the 1286/1296 is that the 1286/1296 can drive lower impedance loads. If loads less than ~2kΩ are required, the 1286/1296 should be used. The high-current drive of the 1286 and 1296 is helpful when driving a low-impedance attenuator as often required to drive low-noise A/D converters, which cannot accept inputs as high as are supplied by the circuit of Figure 10.

Figure 10. Double-balanced differential output.

If a common mode output voltage (Vcm) is desired to drive an A/D converter, the Ref pins on both differential amps may be disconnected from ground (via J1) and connected to a suitable source of Vcm. However, designers should note the relatively low input impedance (~9kΩ) at the Vcm input in Figure 10. To maintain high CMR, it is essential that this node be driven from a near-zero impedance. For most ADCs, a buffer will be required.

While the circuit of Figure 10 is suitable for use as a switched line input (as shown in Figure 7), it has a similar noise disadvantage as the circuit of Figure 8, due to the relatively high impedances used in the 1286/1296 ICs. The two differential amplifiers appear in parallel at the line input, halving their input impedance to ~12kΩ. This seems an acceptable minimum value for professional audio line inputs.

Like Figure 9, Figure 11 offers lower noise by using a low voltage-noise opamp and low value resistors. This configuration is sometimes seen as a line receiver (see reference 5). U1 is configured as a differential amplifier. Its output is inverted by U2, whose output is fed back to drive the reference leg (R17 and C6) of the U1 differential amp.

The major advantage of the circuit of Figure 11 over that of Figure 10 is that it provides lower noise (comparable to that of Figure 9) due to lower resistor values and its
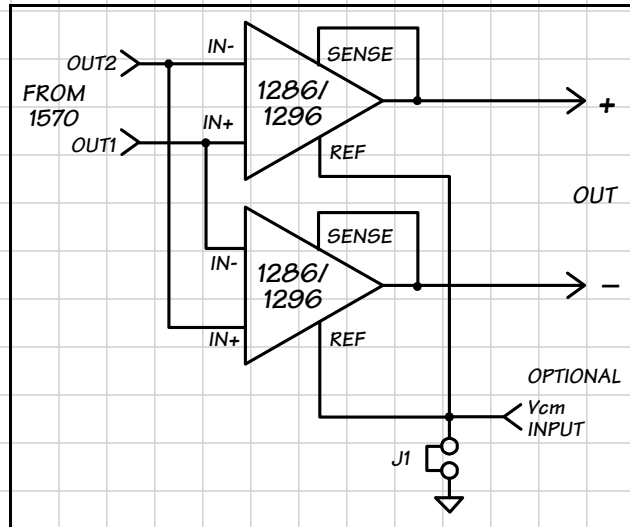

Figure 11. Quieter differential output.

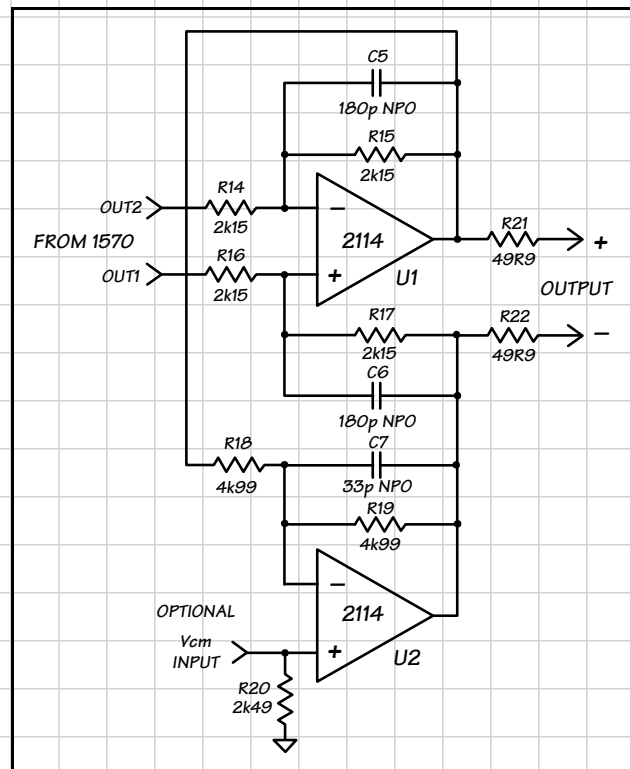THAT Corporation

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unique topology. Additionally, while U2 does add noise, the clever connection to the reference input of U1 forces U2's noise to appear in common mode at both outputs. As long as subsequent circuits have more common-mode rejection than U2 adds common-mode noise, there is no noise penalty from the inversion. (Modern differential-input A/D converters generally have enough common-mode rejection to satisfy this requirement.)

Due to the relatively low values of R14~R16, which lowers the input impedance, this circuit is not recommended for switched line inputs as shown in Figure 7.

The values shown in Figure 11 produce 0dB (unity) gain from input to output. Like the circuit of Figure 9, gain may be scaled to suit different requirements. It also offers a convenient node at which to inject Vcm. Because Vcm is connected to the high-impedance positive input of U2 (with R20 removed), a buffer is not generally required between the A/D converter common-mode reference and Vcm in Figure 11.

As with the other discrete circuits, common mode rejection of this circuit is limited by resistor matching. As with the circuit of Figure 9, worst-case CMR with 1% resistors will be 31.5dB, improving to 51.5dB with 0.1% resistors.

For best transient response, the compensation capacitors for the differential stage (C5 and C6) must be made larger than the compensation of the inverter C7. (The point is to ensure that the inverter is faster than the differential stage). With the values shown the −3dB point of the entire circuit is ~410 kHz and the transient response is outstanding. If C5 and C6 are made too small, or if C7 is made significantly larger, overshoots will occur.

A Complete Preamp with Polarity Reverse

The circuit of Figure 12 combines the input and output circuits described in Figures 1 and 7, along with a switch to provide polarity reversal. It has high common-mode rejection for both mic and line inputs, and provides appropriate input impedance for both input types. Polarity for both mic and line inputs is controlled by SW4 in front of the 1246.
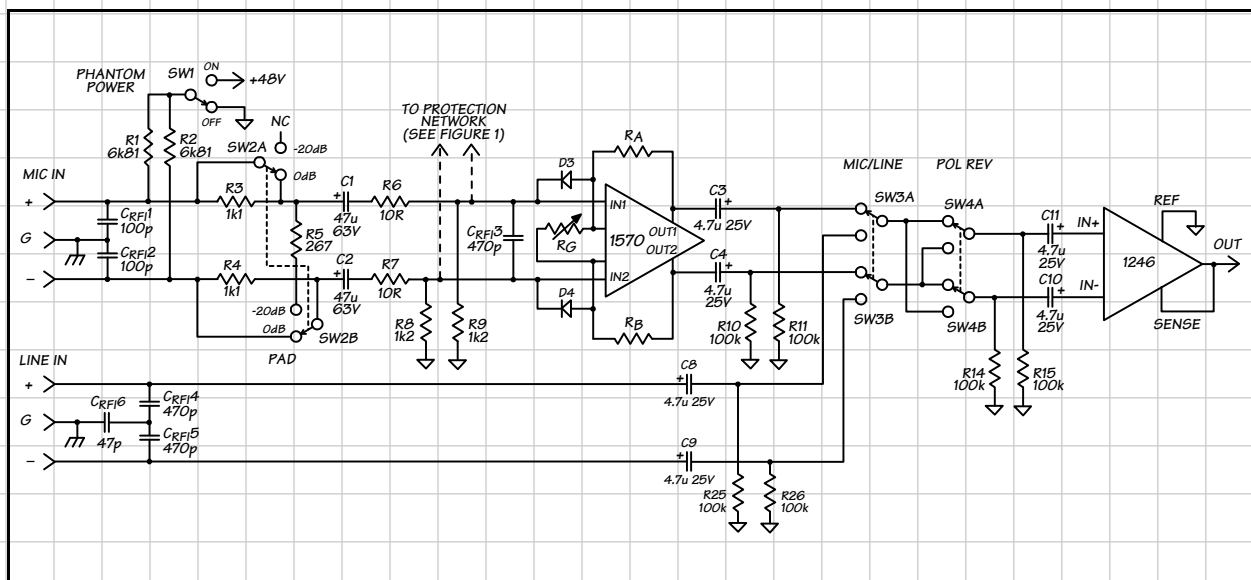

Figure 12. Complete preamplifier with high CMR, single-ended output, and polarity reversal.

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