Optical DAA2000 Theory of Operation
Appnote 71

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Introduction

The DAA circuit, known formally as the "Digital Access Arrangement," is the physical connection to the telephone line known as the "local loop." The DAA performs four critical functions:

1. Line termination
2. Isolation
3. Hybrid
4. Ring Detection

The following is a description of how the Infineon optical DAA circuit fulfills these requirements, as well as providing other useful features. The DAA2000 can fulfill a wide variety of telephone interface applications including voice, FAX, and data. This application note assumes the DAA is used as the interface to a data modem.

General Architecture

The DAA block diagram is shown in Figure 1. This is a simplified schematic showing how the circuit operates.

The circuit is broken into two parts; the Line side circuit and the Modem side circuit. Telephone regulations require a high voltage barrier between these two sides which is provided by the analog opto-isolators.

The Line side circuit derives its operating power from the telephone line directly. A bridge rectifier allows operation from either battery polarity. A fuse and a high voltage transient protection device are used to preserve telephone line integrity in the event of a lightning, or other high energy pulse coming in from the loop.

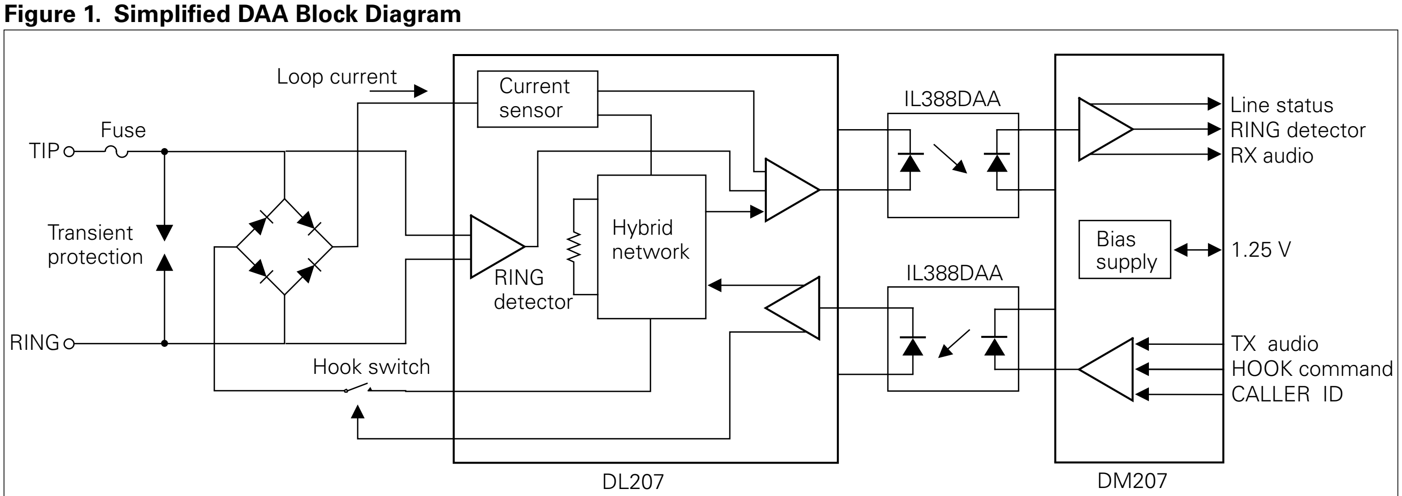
The DL207 Line side chip includes a HYBRID circuit that separates the TX and RX signals by doing a 2 wire to 4 wire conversion. The success of this circuit (trans-hybrid balance) depends on the line termination impedance shown in Figure 1 as a simple resistor. In fact, the termination impedance is a combination of an external resistor and an external capacitor. The value of these components depends on the telephone regulations of the country concerned.

The RX audio signal is transmitted across the high voltage barrier with an analog opto-isolator. This circuit is capable of very good linearity and broad bandwidth by using a novel feedback technique. In a similar circuit, the TX audio is passed across the barrier with a second analog opto-isolator.

On-hook and off-hook functions are taken care of by turning on/off the series switch. In the DAA circuit, this is a DMOS transistor capable of withstanding at least 350 V. When in the "on-hook" condition, the switch is open and the DAA draws no current from the loop. The DAA can be commanded to go "off-hook" by asserting the "hook command" input to the DM207. This command is communicated to the DL207 via the IL388DAA analog opto-isolator. An internal multiplexing operation takes place which combines this command, the Caller ID command, and the actual TX audio signals. When the off-hook command is given, the DL207 switches on the hook switch by fully saturating the DMOS transistor.

The Caller-ID function is sometimes referred to as the "snoop" mode. When this command is given, the DL207 turns on the hook switch just a little. In this mode, the loop current is kept

Figure 1. Simplified DAA Block Diagram



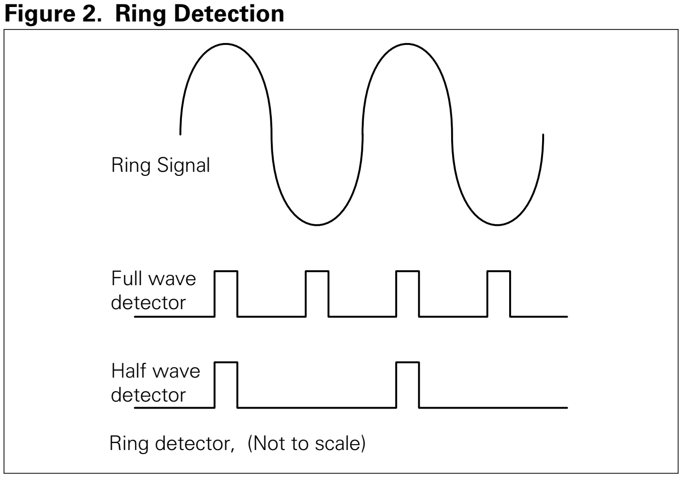
low enough to keep the central office (CO) from seeing an off-hook situation, yet it allows the DL207 to transmit the RX audio signal over to the DM207.

When in the "off-hook" mode, the DL207 passes the full loop current through itself. Power for the chip is derived by an internal circuit which acts like a Zener diode. The voltage across the chip from V_{DD} to V_{SS} is maintained at about 5 V. With the hook switch fully "on," loop current is determined by the external loop resistance. In some countries, the current must be limited to 60 mA maximum by the DAA. In those cases, an external current limiting circuit must be added.

To prevent damage when the DAA is accidently connected to a digital PBX line with unlimited current capability, the DAA has an internal shut-down circuit. This circuit is sensitive to total power dissipated by both hook switch and the DL207, and internal temperature. When power from the line exceeds about 3 to 4 watts at room temperatures, the DL207 turns off the hook switch. In this situation the hook switch itself can generate significant heat. Therefore the switch should be thermally connected to the DL207 with ground plane techniques. This shutdown function is linearly de-rated to 50 mA at +70°C.

A ring detector is built into the DL207, which can be configured as either a "full wave" detector or a "half wave" detector. In the full wave mode, a pulse is generated at the DM207 "ring detect" output pin for each half cycle of the ring signal. In the half wave mode, one pulse is generated for each full cycle of the ring signal. See Figure 2.

Figure 2. Ring Detection



Using Optical Isolators for Crossing the Barrier

For many years, the only practical solution to providing high voltage isolation between the CO loop and the modem (or any telephone device) has been the use of a transformer. In modern equipment design, space, weight, and cost are all prime concerns. The venerable transformer does not fit into today's solutions. Optical isolators can provide excellent high voltage isolation in a very compact size. The IL388DAA devices have a 2500 V rating.

The use of linear opto-isolators is a well-established technique in instrumentation designs. Infineon uses this same basic idea in the DAA2000 by using standard, off-the-shelf linear opto-isolators with their custom linear chips, the DL207 and DM207. The way this circuit achieves such good linearity is by using matched detectors in the IL388DAA with one used in the feedback circuit, and the other used to cross the barrier.

Figure 3. Matched Detectors

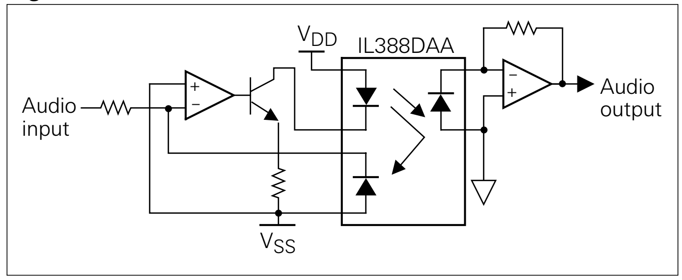


Figure 3 shows the method of using matched detectors. In this circuit, the audio input signal is dropped through the input resistor to virtual ground. The op-amp output drives a transistor, which draws current through the LED. The source side photo-diode generates a current which goes back to the input source and closes the loop. The closed loop linearizes the LED. The secondary side photo-diode is an exact duplicate of the first and is illuminated with the same light from the LED. In the output op-amp, the photo-current generated is forced to flow through the feedback resistor. That generates a voltage equal to the original input signal.

The DAA circuit uses this same principle of matched detectors. Figure 4 is the DAA version, which also includes the hybrid function. The complete signal details are not shown for simplicity.

The Hybrid Circuit

The hybrid circuit operates by modulating the loop current with the TX audio signal. This can be seen in Figure 4. The TX audio current is generated in the lower opto-isolator in the secondary photo-diode. That current is impressed across a 600 Ω and a 1200 ohm series pair of resistors. The voltage generated across the 1200 ohm resistor modulates the current flowing through R1. This external resistor is normally 16.5 Ω, but the value can change slightly as needed for other than 600 ohm termination impedances. R1 also affects transmit gain and trans-hybrid balance.

The receive audio signal is picked up with the induced voltage across the 3600 ohm resistor. This, of course, also has the TX signal as well. The TX signal is cancelled by feeding an equal but opposite amount of the original TX signal into the summing amplifier at the top. The balance of this cancellation is dependent on the matching accuracy of the resistors shown. All resistors except for R1 are internal to the DL207, and they are matched in ratio to a very high degree and will accurately track over temperature.

The balance is also referred to as "trans-hybrid loss." Effectively, this is the amount of RX signal which gets inadvertently fed into the TX signal path. If the match is perfect, then the trans-hybrid loss is infinite. Typical DAA2000 applications have a trans-hybrid loss of around 20 to 30 dB, which is far better than traditional transformer circuits.

Audio AGC Compensation

Optical isolators can have gain variations that change with temperature and age. To compensate for these variations, the Infineon DAA2000 has an internal AGC circuit, which adjusts the audio gain based on measured DC gain characteristics

Figure 4. Trans-hybrid Circuit and Optical Coupling

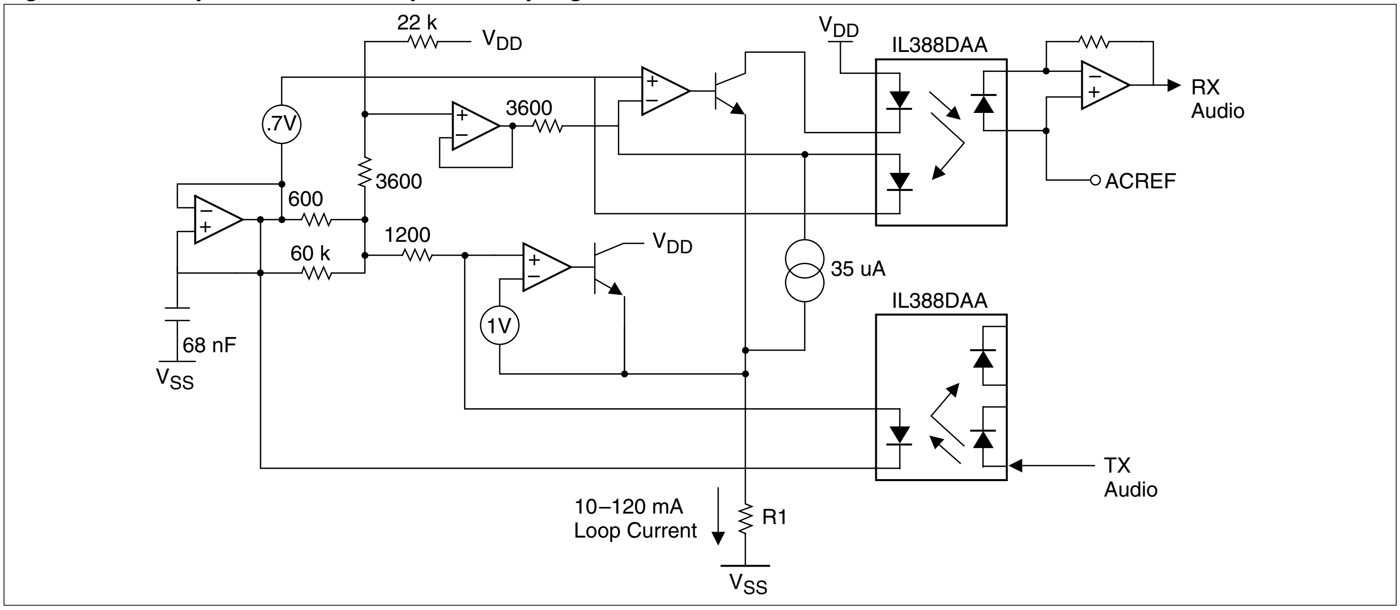
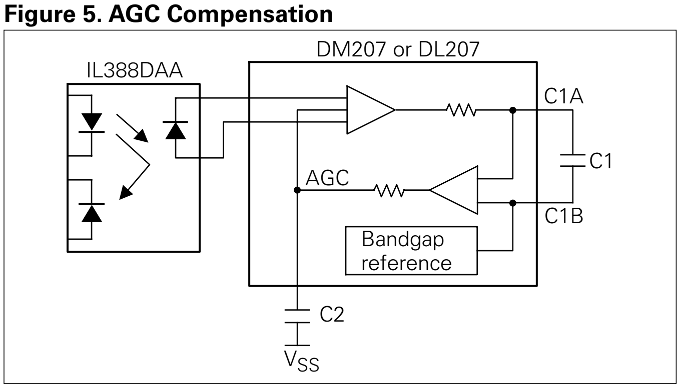


Figure 5. AGC Compensation



The AGC circuit works by adjusting the gain of a low distortion, variable gain current amplifier so that the average photo-diode output DC current is constant. This has the effect of normalizing the AC gain at the output since the AC gain strictly tracks the DC gain of the linear optical isolator. DC averaging is provided by a low pass filter whose time constants are set by C1 and C2. With the values recommended in the reference circuit, the time constant is about 400 mS. Increasing the values of the capacitors will improve low frequency distortion, but will increase settling time. The ration of C2 to C1 should be kept at 4.5 to 1 to provide optimum damped settling.

Note that there are similar AGC circuits in both the DL207 and the DM207. In both chips, the AGC functions on the "received" audio from the opto-isolator. In the DL207, this is actually the TX signal to be transmitted into the loop. In the DM207, it is the RX signal received from the loop.

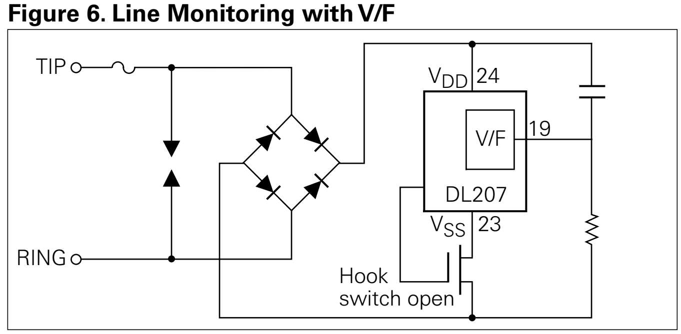
On Hook Operation

In the "On-Hook" condition, the DAA appears as a very high impedance and draws only a few microamperes of line current.

A V/F (voltage to frequency) circuit monitors the open line voltage. This voltage measurement appears at the DM207 at pin 23, LSTAT in the form of a series of pulses. Each pulse is about 4 mS wide, and the frequency of the pulses is proportional to the line voltage. The pulses are sent across the barrier by pulsing the RX opto-isolator during the discharge time of the RC circuit.

Gain of the converter is based on two external components connected to pin 19 of the DL207. Given the reference values of 20 MΩ and 68 nF, the gain of this circuit is about 0.5 Hz/volt. The resistor value must not be lower than 10 MΩ otherwise the circuit will not meet FCC part 68 on-hook DC resistance specifications. The capacitor may be varied between 10 and 100 nF with resulting change in pulse width and V/F gain.

Figure 6. Line Monitoring with V/F



This circuit is provided to allow detection of line status without having to go off-hook. It can be used to detect when an extension phone goes off-hook, or if the modem is connected to a dead line. Most modem problems are improper connection to the line.

Due to the wide variety of other telephone equipment available, it is not possible to reliably determine line condition by monitoring line voltage alone. Generally, line voltages below 12 to 14 V indicate the line is in use. Voltages above 18 to 20 V indicate the line is available. Voltages in the 12 to 20 V range are ambiguous. This is because telephone standards have no maximum off-hook voltage drop recommendations for line currents over 26 mA. A common situation where a high line voltage is encountered while the line is in use, is when a user has inserted a zener adapter in series with their answering telephone jack to improve answering machine cutoff. These zener adapters will typically increase the answering machine off hook voltage to above 14 V.

A solution to the voltage ambiguity problem is to design firmware, which looks for a change in line voltage, or keeps a history of line voltage to determine normal idle voltage. Then a trip point can then be set about 30% below that idle level.

If the V/F function is not needed, the components connected to pin 19 of the DL207 can be left out. Note that the V/F does not function when off-hook, or in SNOOP mode.

Snooping

Asserting either the SNP input (or the inverse SNPL input) on the DM207 puts the DAA into SNOOP mode. This is used primarily for Caller ID purposes. When in SNOOP mode, the DAA pulls about 600 uA from the loop. Line voltage must be at least 3.5 V. This current is much less than what the CO would consider going off-hook, which is usually at least 5 mA. SNOOPing does not violate FCC part 68 rules as long as it happens during ringing, or when another telephone device is off-hook on the same line.

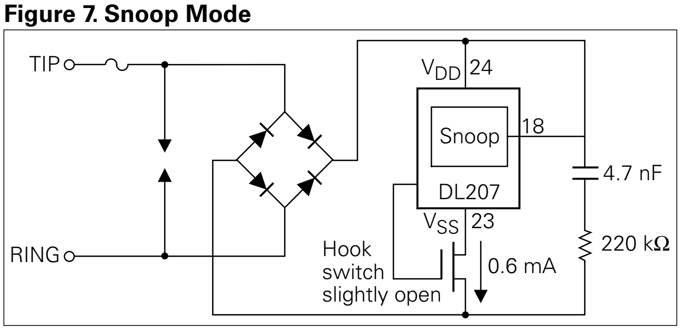
SNOOP mode is an option, which requires adding an external RC network. This is typically a 220 k resistor in series with a 4.7 nF capacitor from pin 18 of the DL207 to the negative terminal of the bridge rectifier. When active, the AC line impedance is roughly 220 kΩ.

In a typical Caller ID application, the modem firmware will assert one of the Snoop control lines following the first ring so as to pass the Caller ID burst of DTMF tones to the data pump for detection.

In a Voice/FAX/Data application, a Snoop control line is asserted during the ringing and for perhaps 15 to 60 seconds after the telephone line is answered by an external extension telephone (when ringing stops). The modem then listens for FAX or Data calling tone or DTMF sequence. If a tone is recognized, then the modem firmware can answer the call.

This steers the FAX or Data call from the answering machine, which initially answered the call, to the modem.

Figure 7. Snoop Mode



In call logging applications, Snooping should be asserted if the V/F circuit detects the line has gone from idle to in use. This allows the modem to monitor and detect the DTMF dialing, then pass the dialed number to the host computer for logging. The V/F function will also allow the host computer to measure call duration.

Note that the V/F line monitoring circuit described above operates differently when in SNOOP or OFF-HOOK modes. Normally, the LSTAT pin goes low and stays there.

If the line current drops to zero, LSTAT will go high for as long as there is no loop current. This can occur if the line is dead (most common problem). It can also happen if the CO drops the line momentarily to indicate remote party hang-up, or for about 1 second prior to the "Please hang up now!" message.

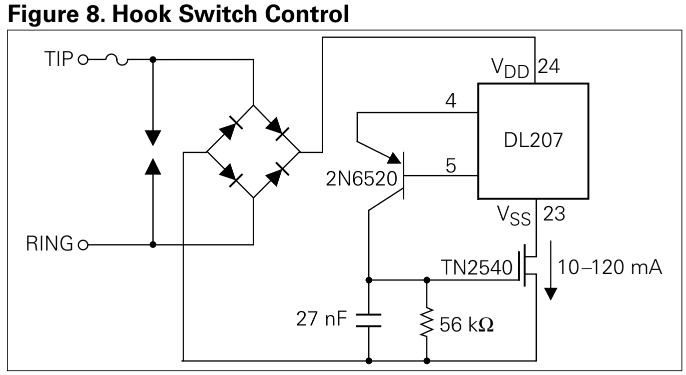
Off-Hook Operation

The DAA is commanded to go off-hook by asserting either the OFFHK (pin 20), or the OFFHKL (pin 21) on the DM207. This is transmitted to the DL207 via the TX analog opto-isolator.

The DL207 immediately switches on the hook switch circuit. The DAA will have an initial off-hook voltage about 2.2 V less than the steady state value for about 200 mS. This low voltage turn-on was designed to satisfy telephone regulations in certain countries. It also is useful in forcing another telephone device, such as an answering machine on the same line, to release the line.

The AGC capacitor C2 sets this turn-on delay. The value can be increased to get a longer turn on delay, but the settling time of the DAA will also increase. C1 must also increase to maintain a constant C1/C2 ratio. See the AGC description above.

Figure 8. Hook Switch Control



The hook switch is a high voltage, low resistance DMOS transistor. The gate voltage must be switched between the extreme negative terminal of the diode bridge, and V_{DD} of the DL207. When off-hook, there may be quite a high voltage across the DMOS transistor. The DL207 cannot control such high voltages, so it utilizes an external high voltage PNP transistor to switch the gate. Both the DMOS and the PNP devices should be rated above 350 V.

The turn-on and turn-off transitions of the hook switch are controlled by the RC network between the gate and source of the FET. The particular values of 27 nF, and 56 kΩ is a compromise which can pass most telephone regulations for "rotary" pulse dialing wave forms.

Line status monitoring in the off-hook mode is similar to SNOOP mode described above. In addition, the LSTAT pin will pulse high for 5 to 50 mS if the loop voltage drops significantly indicating a parallel telephone device has gone off-hook. In order for this local phone pickup detection to occur, the line voltage needs to drop at least 1.0 V at a rate exceeding 30 V/s. Some telephone devices which have high holding voltages or whose holding circuits have very slow turn on rates (high inductance) may not cause the line voltage to drop sufficiently or rapidly enough to be detected.

Audio Interface

On the DM207, there are separate audio TX and RX ports. The TX port is a high impedance input (TXAMP, pin11) which operates with respect to the ACREF, pin 18. The RX port is a single ended output, RXOUT on pin 19. Figure 9 shows a sketch of the audio interface.

Figure 9. Audio Interface on the DM207

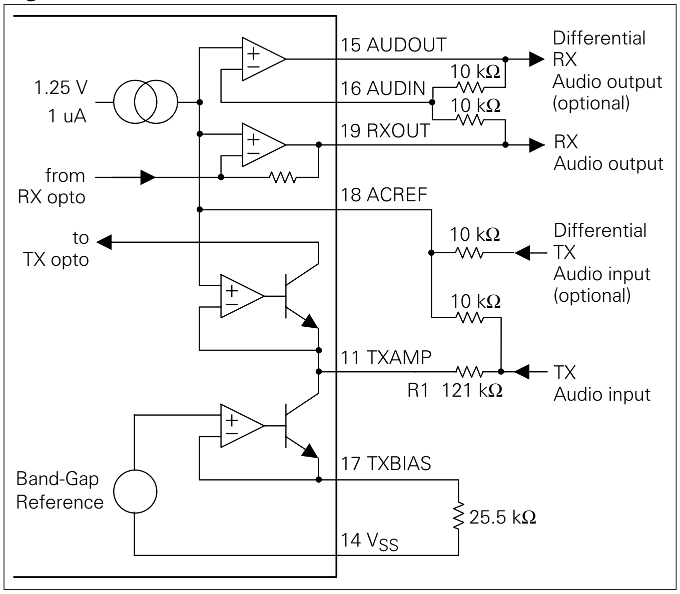
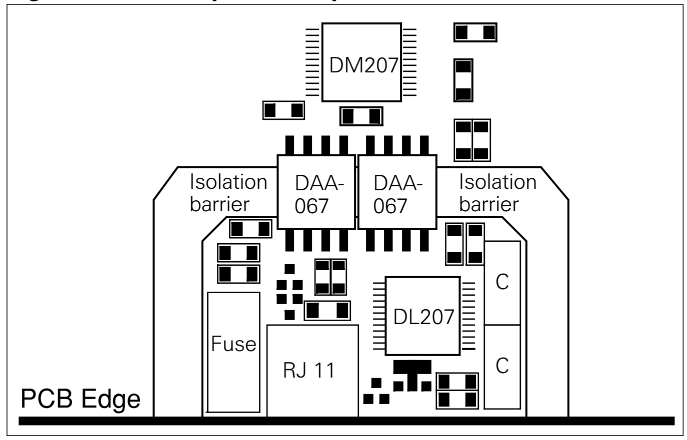


Figure 10. PCB Layout Example



Using external resistors, plus an extra internal op-amp, the RX output can be made differential. If this extra op-amp is not used, leave the input and output pins open (pins 15 and 16)

The ACREF, pin 18, is the internal bias supply for the DM207, and is made available should the designer wish to tie this bias with the data pump bias. The ACREF signal itself is a 1.25 V bias supply with very high impedance. Do not draw more than 1.0 uA of current. If a different bias voltage is being used with the data pump, then that external reference can be connected directly to ACREF.

The TX drive signal can be differential if desired by adding two external resistors as shown above. It is assumed the source impedance is less than 100 Ω.

The TX gain can be adjusted by changing the value of R1. The value shown gives unity gain from the input to the line side (in dBm, relative to 600 Ω). On a voltage basis, the TX gain can be calculated by:

$$\text{Gain}=140/(R1 + 20) \qquad R1 \text{ in k}\Omega$$

Layout and Construction

The two most important aspects to consider when designing a DAA are noise, and isolation.

Electrical isolation is the easier topic to understand and deal with. Most telephone specifications require very high voltage isolation between the loop circuit and the user circuit as a safety issue. The Infineon DAA2000 design uses opto-isolators to achieve an isolation barrier of up to 2500 V.

This isolation can only be realized if the circuit board design and construction is also capable of withstanding this kind of high voltage. The line side circuit should be physically separated from the user (modem) side circuit with at least a 0.2 inch (5 mm) wide gap. The two opto-isolators must be the only components to straddle the gap. Ideally, the line connection (usually an RJ-11 jack) is mounted on the edge of the PC board and surrounded by the line side components, including the DL207. The amount of circuitry will depend on the specific application, and which country requirements are being designed. All other circuitry, including the DM207 must be located on the other side of the gap. Figure 10 shows an example.

It is important that no conductive material be inside, or under the barrier. If the PCB is a multi-layer design, insure that ground or voltage planes do not pass under the barrier.

Noise is the other major layout related issue. A compact layout similar to Figure 9 is also very good at keeping induced noise to a minimum. Being an analog circuit, the Infineon DAA2000 will not generate significant noise by itself. However, the circuit can (and will) pick up noise generated from nearby digital circuits. Keeping the line side circuits inside a small, tightly designed isolation barrier as shown will minimize noise pickup. Using a separate ground plane for the line side components is usually not needed. In fact, ground planes can be highly detrimental if ground loops develop. If there is to be a ground plane, then connect it only to the DL207 V_{SS} on the line side pin.

A common problem with noise pickup is when the DM207 is interfaced to a modem data pump IC (or other applications). Be sure that the ACREF, pin 18, is well by-passed with at least a 0.1 uF high frequency capacitor. In some applications, a 10 uF tantalum may be needed. Similar bypassing of the V_{DD} pin is also good engineering practice.

In some applications, digital noise can be injected into the DM207 via the control pins (such as OFFHK or SNP). If this happens, try adding a 3.3 kΩ resistor in series with the line and a small bypass capacitor at the DM207 input pin.

Another potential problem is the need to reject local RF pickup from the telephone line itself. The local loop, being a very long pair of wires, is an excellent receiving antenna. Local broadcast and TV signals will inevitably find their way into the DAA from the loop. Prudent designers will add the necessary components to reject such interfering signals. Techniques for RFI reduction include adding a ferrite bead to the loop wires directly adjacent to the RJ11 connector, and adding ferrite beads to the DAA circuit itself, in conjunction with high voltage by-pass capacitors. Some international telephone specifications require such RFI filtering.