Signal and noise levels underline ADSL line driver, receiver design

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Designing the analog portions of the transmit and receive channels in ADSL systems is a sometimes complex procedure that must take into consideration the signal levels in the channel, the noise levels, and the frequency spectrums involved. This article reviews overall design guidelines for implementing the analog interface circuitry used in ADSL line drivers and receivers. We present here a general overview of ADSL, emphasizing those system requirements that directly influence the design of the analog circuits. Several line driver circuit topologies are reviewed to present a chronology of line driver circuits as they evolved during ADSL deployment. Different line receiver circuits, hybrids, and coupling transformers will impact the overall system performance. Engineers would be particularly interested in signal dynamic range, power dissipation, noise performance, and distortion generated by these devices.

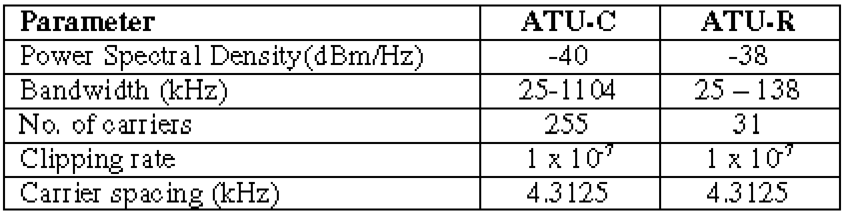
The asymmetrical digital subscriber lines (ADSL) interface is a communication protocol used to transmit high-speed data (and potentially voice data) over the existing two-wire telephone line infrastructure. The data rates are asymmetrical. Data originating at the telephone company's Central Office (CO) is sent 'downstream' to the customer premise equipment (CPE) or remote terminal (RT) end of the line at data rates up to 1.5 Mbits/sec. Data sent in the reverse direction, from the RT to the CO, is referred to as 'upstream' data. Upstream data typically has a maximum data rate of 150 kBits/sec.

The asymmetrical nature of ADSL was originally conceived because of the asymmetrical nature of data flow for such requests as video. The user makes a simple request for a movie and the resulting downstream data flow is at a high rate to support video. This is also a typical data flow for Internet access. A user requesting a web page needs only a minimal data rate to support that request. However, for acceptable performance, the downstream data containing the web page (or file) must load quickly, thus the need for a higher speed data rate in the downstream direction.

Relative T1.413 Specifications 1

Delivering optimum performance for ADSL signals over all variations of the environment requires careful attention to detail in the design of the analog transmit and receive circuitry at both ends of the line. The detailed requirements for full rate ADSL performance is specified in ANSI T1.413-1998. Each of the major ADSL specifications that directly impact the circuit design (and performance) from this specification is detailed below. ATU-C refers to the Central Office end of the phone line and ATU-R refers to the remote, or client, end of the line. The designer needs to consider all the parameters for a successful design.

Table 1. ADSL Specifications



Parameter	ATU-C	ATU-R
Power Spectral Density(dBm/Hz)	-40	-38
Bandwidth (kHz)	25-1104	25 – 138
No. of carriers	255	31
Clipping rate	1×10^{-7}	1×10^{-7}
Carrier spacing (kHz)	4.3125	4.3125

Signal Power -- Signal power for both ends of the line is controlled by the T1.413 specification. As shown in Table 1, the maximum power density of the ATU-C signal is given as --40 dBm/Hz. With a subcarrier bandwidth of 4.3125 kHz and a maximum number of carriers used of 255, the maximum aggregate power can be calculated to be 20.4 dBm. This maximum aggregate power is also defined in the T1.413 specification. This is necessary because there are exceptions permitted to the power spectral density (-40 dBm/Hz) specification under certain conditions, however, the maximum aggregate power requirement of 20.4 dBm must be adhered to. This RMS power number will be used later to determine the maximum peak voltage and a current level required at the line driver output and thus is a critical design parameter.

Similarly, the average aggregate power can be calculated for the ATU-R side of the line. The specification sets the maximum power spectral density at --38 dBm/Hz. With a 4.135 kHz bandwidth per subcarrier and a maximum number of subcarriers of 31, the total aggregate power can be calculated to be 12.5 dBm. As with the ATU-C case, the specification also defines 12.5 dBm as being the maximum allowed aggregate power on the line because of exceptions allowed to the power spectral density under certain conditions.

Bandwidth -- Spectral management plays an integral role in the overall performance of an ADSL system. A typical DSL system contains a cadre of filters, both digital and analog, for processing the data. From a line driver/receiver perspective, the important issues are power spectral density and intermodulation issues with these issues more critical for the CO driver because it operates at the higher frequency.

Clipping rate -- This refers to the probability of bit error caused by the output of the line driver amplifier clipping. Actually the term clipping is a bit of a misnomer. Bit errors will begin to occur before clipping, because as the amplifier output voltage increases, non-linearities in the signal will begin to increase. These non-linearities will cause waveform distortion which will then cause intermodulation products that lead to bit errors.

Consequently, the line driver circuitry is implemented with distortion in mind rather than clipping. The designer's goal is to achieve full output voltage swing with acceptable distortion levels that supports the desirable system peak to RMS ratio (PAR) level of the output voltage waveform.

Line Length -- One of the most telling parameters of system performance amongst competing ADSL suppliers is the term 'reach'. Reach is synonymous with telephone line length and simply indicates over what distance the system continues to operate at its specified bit error rate performance.

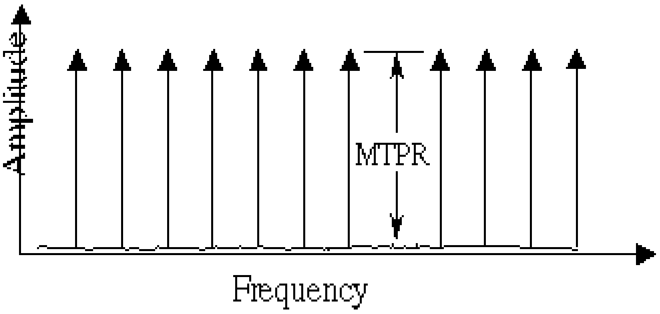
Of course line length has a direct impact on the design of the analog circuitry. Line length impacts the expected minimum signal-to-noise ratios because of the signal attenuation for long lines. In addition, the variation of line lengths from minimum to maximum directly determines signal dynamic range over which the circuitry must operate.

The T1.413 specification describes several test loops to be used for testing the ADSL system. The maximum line length given is for a test loop that is 5.75 km (18,865 feet) long. However, competing ADSL chip set vendors will often try to establish a reach that is beyond the specification number for marketing/sales purposes.

Line Impedance -- For proper line driver/receiver circuit design, the designer must take into account the complex nature of the impedance of the twisted pair telephone line. Much work has been done developing models for telephone lines using extensive survey data 2.

Distortion -- ADSL is a multicarrier data transmission technique. As such, it relies on well-defined and controlled subcarrier bandwidth to achieve its performance. In a system with multiple carrier frequencies, any non-linearities in those carriers will create intermodulation distortion products. If these distortion products fall within another subcarrier's bandwidth, performance may be sacrificed. This distortion is measured by using the Multi-Tone Power Ratio (MTPR) test shown in Figure 1. All subcarriers are transmitted except one. Then the noise floor within the bandwidth of the missing tone is measured to see how much spill-over is generated from the intermodulation of all other carriers combined. Over the transmission frequency band, the MTPR of the transmitter in any sub-carrier must be no less than 65 dB. This T1.413 specification means that the performance of the amplifier used as the line driver must be linear enough to meet this requirement. Designers should look for amplifiers that are capable of this performance.

Figure 1. Multitone Power Ratio Spectrum



Background Line Noise -- There are many sources of noise within the ADSL system. However, one of the benchmark parameters used to judge performance is the background noise level on the telephone line. This level is typically accepted to be approximately -140 dBm/Hz and was taken from data in a study that Bellcore did of existing phone lines.

Circuit requirements

The next step in arriving at an acceptable circuit design for an ADSL line driver/receiver is the translation of the system requirements into circuit requirements.

To establish the voltage and current levels that the line driver needs to deliver to the line, the nature of the ADSL signal must be examined to determine the relationship between the expected peak values and the RMS value.

PAR-- The term PAR (peak-to-average ratio) is defined to be the ratio between the peak value and RMS value. This is also sometimes referred as the crest factor. For an ADSL system using a DMT (Discrete Multitone) implementation, there is a maximum of 255 discrete subcarrier frequencies all transmitting at the same time. Because each subcarrier is at a different frequency and phase, there will be a statistical distribution of the amplitude of the composite waveform. This distribution will be near Gaussian in nature.

To satisfy the system requirement of voltage clipping occurring with a probability of less than 1*10-7, the circuitry must pass the peak voltages corresponding to this probability. To do this, the system must accommodate a PAR of 15-17 dB. The exact value depends on a combination of hardware and software capabilities. For this paper, a PAR of 15 dB will be used for illustrative purposes. (The reader should be aware that higher PARs place more stringent requirements on the circuit design because higher voltage and current swings are required.)

The voltage and the current on the line can now be calculated. From the previous section, the power on the line at the CO is 20.5 dBm, or 110 mW. Assuming a line impedance of 100 ohms, the resulting RMS voltage is 3.31 volts and the RMS current is 33 mA. With a PAR of 15 dB, or 5.6, the peak voltage is 18.5 volts and the peak current is 185 mA. The values for RT are calculated in the same manner only starting with 12.5 dBm of power on the line. The results are summarized in the Table 2.

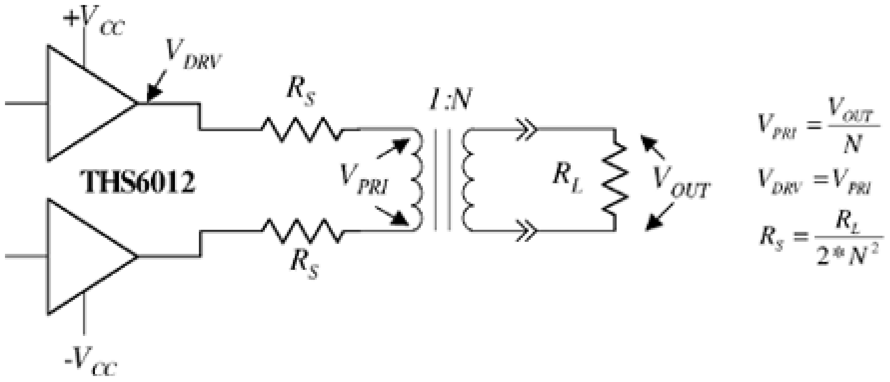
Table 2 - Line Voltages/Currents

	CO	RT
P_{RMS} - mW	110	17.8
V_{RMS} - volts	3.31	1.33
I_{RMS} - mA	33	13.3
V_{peak} - volts	18.5	7.5
I_{peak} - mA	185	75

Circuit topologies

Line Driver - Shown in Figure 2 is a simplified differential line driver circuit. It consists of a differential amplifier, two line matching resistors (RS), and a coupling transformer with a turns ratio of 1:N.

Figure 2. Simplified ADSL Line Driver Circuit



The purpose of the transformer is threefold: (1) It provides a means for amplifying the signal voltage and achieving the high peak voltages required without using exceptionally high power supplies. (2) It is a simple means of combining differential signals and thereby doubling the output voltage. (3) It provides isolation between the phone line and the ADSL circuitry.

By installing resistors in series with the line driver amplifier output, two things are accomplished: (1) The telephone line is terminated with the proper impedance and, (2) signals received from the opposite end of the line appear across these resistors which is explained in more detailed in the following section. When the line is properly terminated, the output voltage required at each amplifier output will be the same as that required across the primary of the transformer. This is because with a matched line half the voltage is dropped across the source termination resistor.

Transformer Turns Ratio - Examining Table 2 for the CO case shows that a peak-to-peak voltage of 39 volts is required on the line. In order that the output of the amplifiers remain within a manageable range of voltage, a step-up transformer turns ratio is required. For example, with a turns ratio of 1:2, the maximum peak-to-peak voltage across the primary (and at each amplifier output) is 18.5 volts peak-to-peak. This is a reasonable range for amplifiers with +/-12 volt supplies. The resulting peak current at the amplifier output is increased by the turns-ratio to a value of 370 mA.

Thus, for CO applications, a transformer makes the voltage levels reasonable but has raised the current levels to more difficult regions. At these higher current levels it is much more difficult to maintain the linearity required to achieve low total harmonic distortion. And in a system like ADSL with its multiple subcarriers, nonlinearity in the signals will create intermodulation amongst the subcarriers and lead to poorer performance.

For a turns ratio of 1:2 a 100 ohm line is properly terminated with 100/4 = 25 ohms in the primary side of the transformer. Splitting this 25 ohms into two 12.5 ohm resistors meets the requirement.

The exact turns-ratio used for the transformer is impacted by several criteria. First, the ratio must be high enough to ensure that the amplifiers can supply the peak-to-peak voltages required by the system. (Recall that the system PAR is what sets the peak-to-peak requirement.) It has been shown 3 that choosing as large a turns-ratio as possible makes maximum use of the line drivers output range and will minimize power dissipation. However, as the turns ratio increases the design must deal with the larger peak current requirements as well as decreased amplitudes of signals received from the other end of the line.

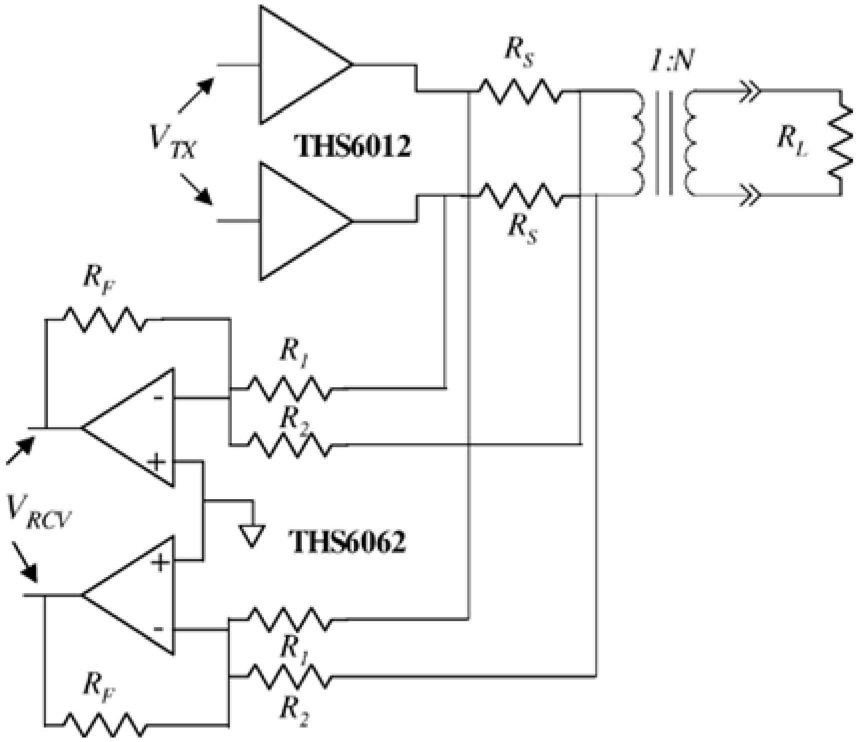
At the RT end of the line, all the same arguments apply in selecting the transformer turns ratio as did for the CO end except for two important differences. First, the power levels put on the line are less, and second, the received signal at the RT end of the line has very difficult signal-to-noise requirements to deal with. Because transformer ratios have a direct bearing on received signal strength, this must be taken into account when selecting the RT turns ratio.

From Table 2 the required peak voltage is 7.5 volts and the peak current is 75 mA. If a transformer with a 1:1 turns ratio is used so that the received signal is not reduced, then the line driver requirement will be to produce a 15 volt peak-to-peak signal at a peak current of 75 mA.

Using the same circuit configuration at the RT that was used at the CO (Figure 2), the voltage requirement at the amplifier output will be the same as required at the transformer primary. For a 1:1 transformer a 15 V peak-to-peak signal is required. This means that a driver should be selected that is capable of handing this output swing at a peak current of 75 mA. Typically, this would result in a amplifier running from +12 and --12 volt supplies because +5 and --5 supplies do not provide sufficient range. If it is desirable to run the amplifier from +5 and --5 supplies, or perhaps from a single +12 volt supply, then the turns ratio would need to change to say 1:2. This would reduce the voltage swing from 15 volts to 7.5 volts and could then be accommodated within the smaller supplies. Of course the amplifier would now need to supply 150 mA of peak current.

Line Receiver/Hybrid - Shown in Figure 3 is a simplified schematic of both the transmit channel amplifiers and the receive channel amplifiers configure in a hybrid connection. The purpose of the hybrid circuit is to separate the transmit and receive signals. Transmitted signals leaving the transmit amplifiers proceed out onto the line via the coupling transformer. However, this signal does not appear at the output of the receive amplifiers because of the configuration of the summing resistors at the receive amplifier inputs. These resistors are arranged so that opposite phases of the transmit signal are summed together so that they cancel.

Figure 3. Simplified ADSL Transmit and Receive Amplifiers



However, in practice, the hybrid does not provide perfect rejection of the transmitted signal. Mismatch of resistors and the line impedance deviating from the ideal value of 100 ohms are causes for the imperfections. In practice, 20 dB rejection of the transmitted signal in the receive channel is about the maximum that can be expected. The variation will be a function of frequency and is strongly impacted by anything that changes the telephone line impedance such as bridged taps.

Although Figure 3 shows the hybrid network as simple resistors, in practice these resistors are typically replaced with R-C networks. This approach more closely matches the frequency dependence of the line impedance. Still, transmitted echo can be expected in the receive channel. In fact, it is often the level of the transmitted echo that determines the dynamic range over which the receive channel must operate, rather than the maximum received signal strength.

Line Driver Topologies

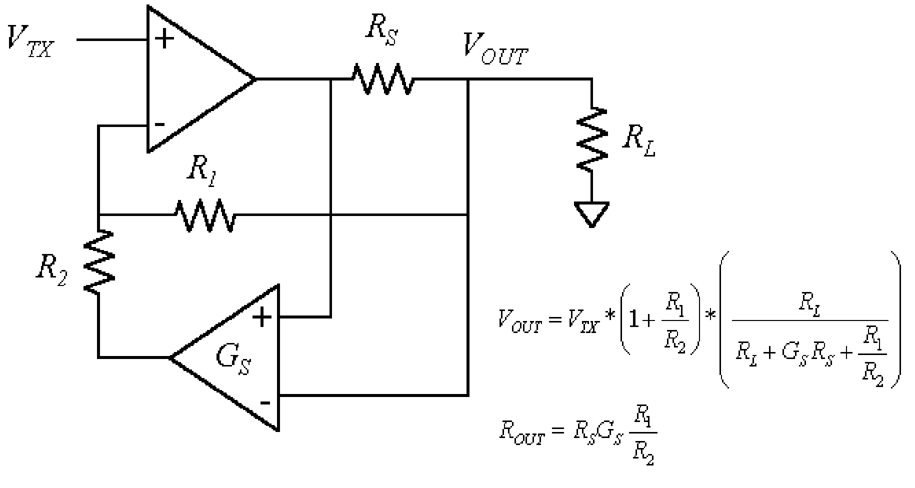
The first CO line drivers to appear on the market were classical Class AB topology devices and were configured as shown in Figure 2. It was not uncommon for some of the earlier devices to dissipate more than 2 watts of power when used as a CO differential driver. For a device that was delivering 100 mW of average power onto the line, this certainly seemed very inefficient.

Several things were responsible for this inefficiency. First, the nature of the DMT signal with its high peak voltages requires that the line driver be powered from large supply voltages such as +/- 15 volts. Second, the series resistors required for line matching and hybrid realization cause a fifty percent drop in the signal amplitude. The last contributor to higher power dissipation was amplifier headroom. This is the overhead voltage required by amplifier for proper linear operation. Collectively all these items caused higher power dissipation in the line driver. While overhead voltage requirements in amplifiers have improved with time, thereby lowering power dissipation, the requirements to support large peak voltages and have series resistors still remains. Nonetheless, the need to decrease the overall power per telephone port was a very strong message from the telephone companies. There was limited power and limited space for deployment. These requirements strongly influenced the direction line drivers would take.

Class G -- To battle the power problem, a high frequency, Class G topology line driver was developed. It operates on the principle that for lower output voltages, the output current is derived from a lower set of power supplies, +/-5 volts. When the demands of the output voltage dictate outputting a higher voltage, the device draws current from the higher power supplies, +/-15 volts. With the nature of the ADSL signal such that it spends the majority of its time at lower voltages, the power savings can be appreciable. What was in the 2 watt region can now be accomplished for about 1.3 watts. Of course, the disadvantage is that two bipolar supplies instead of one are now required. However, this disadvantage can be mitigated across multiple lines on the same PCB card.

Active Termination -- To further reduce the power required by the line drivers, another approach is a technique referred to as active termination or synthesized impedance. In this approach, feedback within the amplifier is used to make the amplifier output impedance match that of the line. By doing this, the line matching series resistor can be eliminated. With this resistor eliminated the voltage drop across it is saved and the line driver can now operate from lower supply voltages thus saving power.

Figure 4. Active Termination Line Driver Schematic



$$V_{OUT} = V_{TX} * \left(1 + \frac{R_1}{R_2}\right) * \left(\frac{R_L}{R_L + G_S R_S + \frac{R_1}{R_2}}\right)$$

$$R_{OUT} = R_S G_S \frac{R_1}{R_2}$$

In Figure 4 is a simplified schematic of an active termination device where only one side of the usual differential pair is shown for clarity. There still exits a resistor, RS, in series with the output. However, its value is typically an order of magnitude less than that used in the classic circuit so the voltage drop across it becomes almost negligible. The following gives the equation for the output impedance and the output voltage:

$$R_{OUT} = G_S * R_S * \frac{R_1}{R_2}$$

$$V_{OUT} = V_{IN} * \left(1 + \frac{R_1}{R_2}\right) * \left(1 + \frac{G_S * R_1 * R_S}{R_2 * R_I}\right)$$

Typical values would be GS=10, RS=1.5, and R1/R2=1 yielding an output impedance of 15 ohms. For a differential circuit with two drivers the total impedance in the primary winding side of the coupling transformer is 30 ohms. When used with a transformer that has a 1:2 turns ratio, this impedance matches a 100-ohm line.

Without the requirement of dropping half the signal voltage across a series-matching resistor, the amplifiers can be powered from much lower supplies. Typically, a single 12 volt supply can now be used. The result is that an active termination amplifier such as this has a typical power dissipation to drive a full rate ADSL signal of approximately 0.8 Watts. A summary of typical power dissipation for the different types of amplifiers used for ADSL line drivers is shown in Table 3.

Table 3 -- Amplifier Power

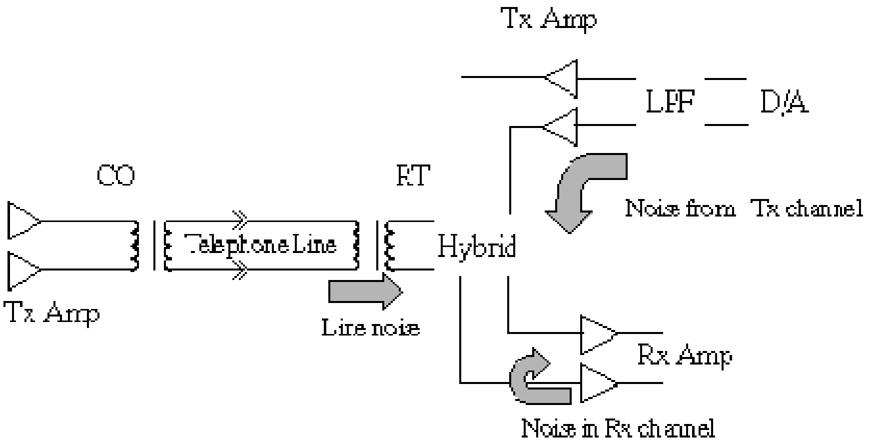
Amplifier Topology	Typical Power (Watts)
Class AB	1.6-2.0
Class G	1.2
Active Termination	0.8

Noise Considerations

In addition to the circuit requirements that effect signal levels and power dissipated, the analog designer must pay careful attention to noise levels in both the transmit and receive channels to achieve a successful design. The receive channel in the RT will be examined in detail from a noise perspective for it is this channel that has the most demanding SNR requirements. This is because the RT receive channel is attempting to receive the highest data rates and needs the best SNR for the best performance

From the standpoint of the RT receive amplifier, the following are all sources of noise that can arrive at the input to the receive channel. Figure 5 shows the location of these noise sources. These include Background noise and In band noise from the CO transmitter from the telephone line; receive amplifier input voltage and current noise (on the receive amp resistors) in the Receive Channel; and D/A quantization noise, amplifier voltage/current noise (on the line driver resistors) on the Transmit Channel.

Figure 5. Receive Channel Noise Sources



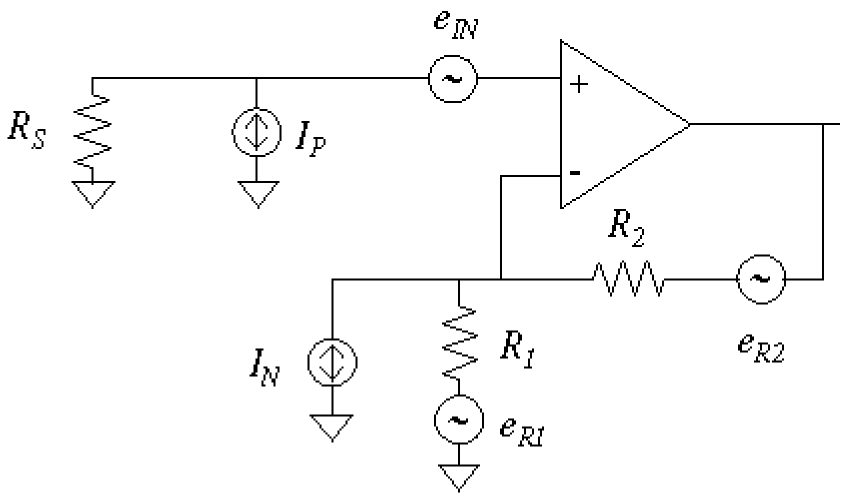
Noise from the line - As described above, the background noise in the line is taken to be -140 dBm/Hz. For a 100 ohm line, this is equivalent to 31.6 nV/rt Hz which becomes the baseline for determining which noise sources are significant and which are not. Each of the noise sources will be examined from the point of view of the input of the amplifier in the receive channel. Thus each noise source will have to be reflected to this point in the circuit. A CO transformer turns ratio of 1:2 and an RT transformer ratio of 1:2 shall be assumed. Thus, the background noise level in the line of 31.6 nV/rt Hz becomes 15.8 nV/rtHz at the input of the receive amplifier.

Assuming the CO transmit amplifier has noise of 2 nV/rt Hz, then both of the amplifiers will contribute the square root of the sum of the squares, or 2.8 nV/rt Hz. Also assuming the amplifiers have a gain of 10, the noise due to the CO transmit amplifiers on the line, at the CO end, will be 2.8*10*2 = 56 nV/rt Hz. However, this noise will be attenuated due to the length of the line. Assuming 40 dB attenuation as an average attenuation for a maximum length line, the noise due to the transmit amplifiers arriving at the receive amplifiers will be 56*0.01*0.5 = 0.28 nV/rt Hz. Thus, this noise is negligible for long lines. For short lines the noise dominates the background noise level of the line, but because of increased signal levels adequate SNR is available and the transmitter noise is not an issue.

RT Transmit Channel Noise - There are two primary noise sources within the RT transmit channel: (1) noise from the line driver and (2) noise generated by the D/A converter. Noise from the line driver consists of noise from the op amp used as the driver as well as all resistors associated with amplifier. In addition, any distortion caused by the line driver can cause intermodulation products within the receive band which is another source of noise. Noise from the D/A is simply the quantization noise generated by its discrete steps of output voltage. Typically, there is filtering after the D/A to help manage how much of this quantization noise will eventually reach the receive channel. Noise generated within the transmit channel will be rejected by the hybrid from entering the receive channel. However, because the hybrid does not do a perfect job of rejection, a quantitative analysis must be done to make sure that all the proper precautions are taken to arrive at an acceptable circuit implementation.

Shown in Figure 6 is a typical amplifier circuit that can be used for the transmit channel amplifier. Noise sources that must be considered are: (1) the amplifier input voltage noise, (2) the amplifier input current noise running through the external resistors to generate voltage noise, and (3) the thermal noise generated by the resistors. The noise generated by resistor R1 is neglected because in a typical differential amplifier configuration this resistor is common to both amplifiers so that its noise cancels out at the differential output.

Figure 6. Noise Sources in a Typical Amplifier Configuration



Typical values for the noise sources are shown in the Table 4. Gains of 10.3 and 5.2 are used corresponding to transformer turns ratios of 1:1 and 1:2, respectively.

Table 4. RT Transmit Amplifier Noise

Source	Initial Value	Output G = 10.3	Output G = 5.2
R_2	3.5 nV	3.5	3.5
e_{IN}	1.7 nV	17.5	8.75
I_N	1.6 pA	1.1	0.99
Total		17.9	9.5

The noise voltage generated by the D/A converter is given as:

$$V_{RMS} = \frac{q^2}{\sqrt{12}}$$

q is the converter LSB step size. Noise density can be calculated by dividing the noise voltage by one half the square root of the sampling frequency. For a typical RT receiver using a 14 bit converter, a 3 volt full scale output, and a 4400 kHz sample rate, the resulting noise density at the input to the RT transmit line driver is 35.6 nV/rt Hz. Considering that this noise density will be multiplied by the gain of the transmit channel line driver, the amplitude of this noise can have a major impact on the receive channel performance. However, the low pass filter following the D/A filters out the majority of noise so for this paper it is assumed that it is negligible. However, the reader should be aware that the low pass filter will provide minimal attenuation at the lower end of the frequency band being received by the RT receive channel.

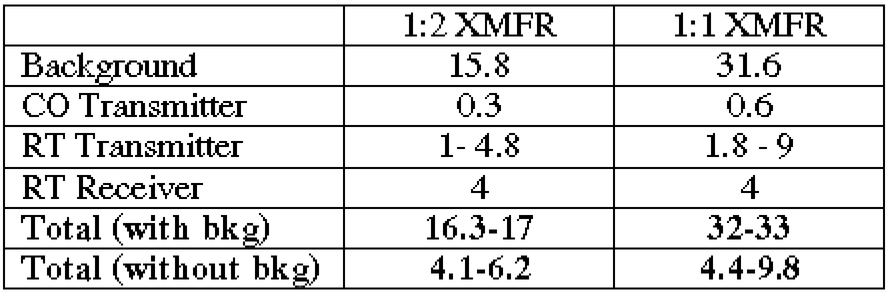
Receive Channel Noise -- The equivalent input voltage noise at the receive channel input will be the combination of (1) the line noise, (2) noise from the transmit channel that is not rejected by the hybrid, and (3) noise generated in the receive channel itself.

Noise generated by the receive channel is from the noise of the input amplifier as well as thermal noise from the supporting resistors. It takes the same form as the noise from the transmit amplifier per Figure 6. It will be assumed that a typical configuration will be used with a low noise amplifier and reasonable resistor values for an overall noise performance of approximately 4 nV/rt Hz.

Table 5 summarizes the noise contributions from each noise source. Examples are given for the two different cases of transformer turns ratio, 1:1 and 1:2. The required difference in gain of the transmit amplifier has been taken into consideration.

It is assumed that the hybrid circuit attenuates noise from the RT transmit channel from 6 to 20 dB. This is a reasonable practical range based on experience. Variations in resistor matching and the wide variation in line impedance from such effects as bridge taps produce these levels.

Table 5. Typical Noises at the RT Receiver



	1:2 XMFR	1:1 XMFR
Background	15.8	31.6
CO Transmitter	0.3	0.6
RT Transmitter	1- 4.8	1.8 - 9
RT Receiver	4	4
Total (with bkg)	**16.3-17**	**32-33**
Total (without bkg)	**4.1-6.2**	**4.4-9.8**

Examination of Table 5 shows that the background noise level of the telephone line dominates the total system noise at the input of the RT receiver. This is proper circuit design because the circuitry has minimal impact on the system performance. The environment limits the system performance.

Noiseless Reach Testing -- In order to evaluate different ADSL chip set vendors, customers may perform a test on an ADSL system that is referred to as the 'noiseless reach' test. The intent of this test is to measure system performance without environmental noise being present. Using telephone lines that are ideal cables does this. These cables have length but do not have the background noise levels that are present in a real telephone line.

Again Table 5 is examined, only this time the background noise is not added into the total noise at the RT receiver input. Now, the system performance may be impacted by several factors. Certainly, the RT Receiver itself will impact the performance and this is to be expected with the dominant system noise source removed. However, other circuitry could limit the system performance in a noiseless reach test. For example, with poor hybrid rejection, the system performance may be limited by the noise generated in the RT transmit channel (even when its not transmitting).

In order to maximize system performance, the designer must pay careful attention to the all sections of circuitry with respect to noise. Low noise techniques must be used in the transmit channel as well as the receive channel to optimize the system reach.

Practical Considerations

Peak ADSL performance requires that the amplifiers being used as line drivers and receivers produce low distortion. Often, the amplifiers with the best distortion performance are amplifiers that use current feedback topology for their implementation. This type of amplifier yields the best slew rates and consequently are the most linear performing parts at high output voltages. However, this type of amplifier can have very high bandwidth, often into the hundreds of megahertz.

In order to successfully use this type of amplifier there are several precautions that should be taken. These are:

- Maintain a very tight PCB layout and minimize all trace lengths to minimize capacitance.
- Remove internal ground planes from underneath the inputs of the amplifier to minimize capacitance.
- Use the feedback resistance value recommended by the amplifier manufacturer. The value of this resistor directly effects the bandwidth.
- Use proper decoupling techniques. ADSL demands large peak currents. The energy to support these large currents needs to come from local decoupling capacitors.

All the requirements from ADSL industry specifications that impacted the circuit design of line drivers and receivers were reviewed. Different classes of amplifier topology and their impact on system power were discussed. Details of all the noise sources within a typical circuit implementation were investigated. It was shown that for 'noiseless reach tests' where the background noise level of the telephone line does not impact the system performance other circuitry (some of which is not obvious) could be the limiting factor. Finally, some practical techniques for using high-speed amplifiers were given.

References

1 ANSI T1.413-1998, "Network and Customer Installation Interfaces -- Asymmetric Digital Subscriber Line (ADSL) Metallic Interface", Issue 2, Dec 4, 1998. 2 W. Y. Chen, "DSL Simulation Techniques and Standards Development for Digital Subscriber Line Systems," Macmillan Technical Publishing, 1998 3 J. Quarfoot, "Optimizing a Line Driver for/Receiver for ADSL Applications, Analog and Mixed Signal Applications Conference, July 1997.