In the last few years, the demand for high speed Internet access, LAN, and short distance data communication have been growing exponentially and growth is expected to continue through the year 2005. Twisted pair, most commonly found in telephone lines, has been used in local area networks to transmit data between data terminals and computers, and for video on demand (VOD) applications. Video designers who want to replace coaxial cable for the more cost effective twisted pair may utilize similar techniques. This transition requires more speed and more integration.

The ever-present problem with pure digital transmission is that it consumes bandwidth far beyond data rates. In response, modem technology has blossomed into a family of digital subscriber loop (DSL) types, collectively referred to as XDSL. Within these DSL systems, analog technology allows a hundred-fold increase of data rate over standard phone line transmissions.

Digital Subscriber Line (DSL) is a blossoming technology with a deployment increasing rapidly among cable model, fiber optics, and satellite Internet access. This discussion will focus mainly on the ADSL CO (central office) driver portion of the system. The analysis and design techniques discussed are applicable to each DSL standard and all driver designs.

After discussing the ADSL DMT CO line driver requirements, we will show typical line driver circuits. From the transformer turns ratio and termination resistor value, we will calculate the driver output current and voltage swing. Then, we will examine the driver linearity and power dissipation. From power dissipation we will calculate the thermal resistance required. Lastly, we will present the power requirements of different ADSL systems and HDSL II system.

The key specifications of ADSL CO driver are as follows: peak output line power is 20dBm, POTS line impedance is 100Ω, and the crest factor for ADSL DMT CO system is 14.5dB.

From output line power and line impedance, we can calculate average output line voltage swing and current:

$$P_{OUT} = \frac{(V_{OUT(RMS)})^2}{R_{LINE}}$$

$$V_{OUT} - RMS = 3.16V$$

$$I_{OUT} - RMS = 31.6mA \tag{EQ. 1}$$

The line peak to peak differential output swing can be calculated with peak to average ratio (PAR), related to the specified crest factor (CF).

$$CF = 20\log(PAR) = 14.5dB, \qquad PAR = 5.3$$

$$V_{OUT(P-P)} - DIFF = V_{OUT(RMS)} * PAR * 2 = 33.52V \tag{EQ. 2}$$

For an ADSL CO output, the peak to peak voltage swing requirement is 33.52V. Peak output current can be calculated by peak output voltage divided by 100Ω line impedance. It is 167.6mA.

The conventional differential pair driver consists of two amplifiers to transmit a differential signal, then the receiver converts the signal back to a single-ended signal. Figure 1 shows a typical differential driver circuit configuration. As calculated previously, the peak to peak output voltage is 33.52V and peak output current is 167.6mA on the line. The output swing on the driver needed to produce this line voltage and current are determined by the transformer turns ratio, N, and back termination resistor value (RTERM). Other key specifications of the differential pair driver and receiver are symmetrical dynamic response, wide bandwidth, flexible
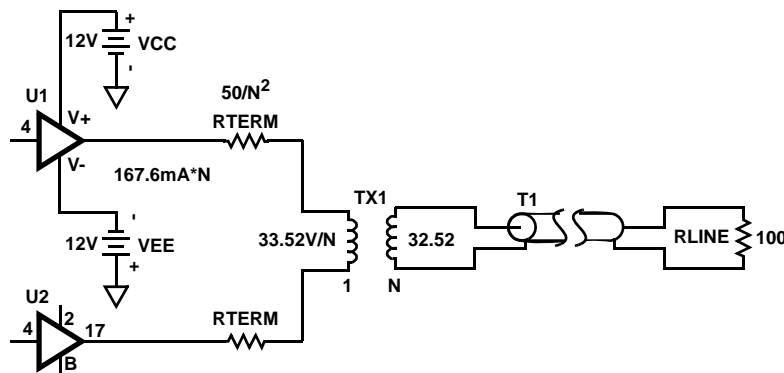

FIGURE 1. DRIVER CIRCUITRY

operation, high output current, and low total harmonic distortion.

The transformer ratio, N, determines the driver output current, voltage swing, and power dissipation. As an example, let's assume N = 1.41, a typical value. The transformer then requires that I_{OUT} - peak for the driver is:

$$167.6mA * 1.41 = 236.3mA \qquad \text{(EQ. 3)}$$

Keeping power constant, the transformer reduces the voltage by the same factor. $V_{OUT(P-P)}$ differential voltage at the driver side of the transformer is:

$$\frac{33.5V}{1.41} = 23.7V \qquad \text{(EQ. 4)}$$

With a two-amplifier, differential drive, the $V_{OUT(P-P)}$ for each amplifier is half of that, or 11.85V.

The output swing at the driver depends on the size of the termination resistor. The termination resistor serves to match the impedance of the line and to dissipate any power reflected back to the source.

For 100% termination, the resistor value is 25Ω. The output swing is 23.7V, with half of the power being dissipated through the termination resistor and the other half reaching the line through the transformer.

The signal strength needed on the line is quantified in the Signal to Noise Ratio (SNR). Many factors contribute, including the resolution of the receiver, the attenuation of the line, and the additional contributors of noise to the system. The first source is telephone loop and plant background noise and the second source is crosstalk from multiple twisted pair in same sheath. Crosstalk disturbances are acceptable for voice but harmful to DSL running at higher frequencies. The resulting SNR is frequency dependent because attenuation and crosstalk are frequency dependent. The worst case, SNR determines the channel capacity of the system.

With 1.41 turns ratio and 100% termination resistor value selected, power dissipation can be calculated for an example driver, the EL1503. Given supply voltages Vs = ±12V, full power mode selected [C_0, C_1 are low], and R_{SET} chosen to be 1.5kΩ, the positive supply current is 12mA. The negative supply current is 11mA. We can now calculate the quiescent power dissipation:

$$P_D(quiescent) = V_S + *(I_S + - 7mA) + V_S - *(I_S - - 7mA) \qquad \text{(EQ. 5)}$$

(where: 7mA is the quiescent current going to the output while driving a heavy load.)

From this equation, the quiescent power dissipation is 108mW. The power dissipation of the output stage can be calculated from supply voltage (minus the RMS output voltage) multiplied by the output current. The total power dissipation is 984mW. With 984mW of driver power dissipation and 100% termination back-matching resistor, the efficiency is 9.5%. Maximum operating die temperature is set at 150°. The maximum ambient temperature is assumed to be 85°. The maximum junction to ambient thermal resistance required is 66.3° per watt.

Table 1 lists key power requirements for the current, and most popular, DSL systems. The design method that has been discussed is equally applicable for these, and any other, DSL systems.

TABLE 1. DSL SPECIFICATIONS

	ADSL C0 FULL RATE	ADSL C0 G. LITE	ADSL CP	HDSL II
Line Power [dBm]	20	16.3	13	16.5
RMS Line Power [mW]	100	43	20	44.7
Line Impedance [Ω]	100	100	100	135
RMS Line Voltage [V]	3.1	2	1.4	2.46
RMS Line Current [mA]	31	21	15	18.2
Crest Factor	5.3	5.3	5.3	3
Peak-Peak Line Voltage [V]	33	22	15.2	14.8
Peak Line Current [mA]	170	110	76	54.7

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