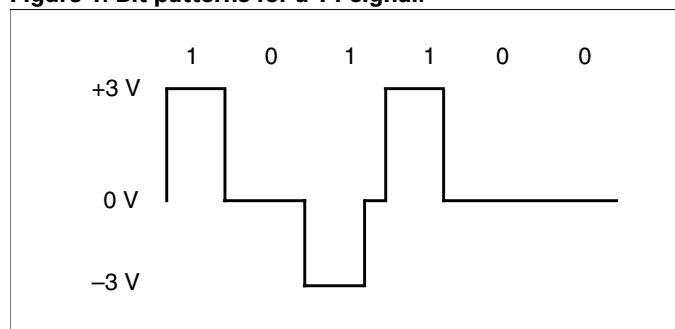## Introduction

The T1 carrier enjoys wide application. As a transmission standard developed in the early sixties, it has survived over three decades of network growth. It is a four-wire transmission medium (two transmit, two receive) consisting of twisted-pair transmission lines, typically using 22-gauge wire, and often bundled with one common shield for all carriers. Its primary application is at the DS1 data rate of 1.544 Mbits/s, where 100 Ω characteristic impedance line is employed. In Europe, there is a related data rate at 2.048 Mbits/s (DS1A). Data rates of 3.152 Mbits/s (DS1C), 6.312 Mbits/s (DS2), 44.736 Mbits/s (DS3), 139.264 Mbits/s (DS4NA), and 155.520 Mbits/s (STS-3) are also common in North America [1].

DS1 signaling on a T1 line typically follows an alternate mark inversion (AMI) format which is illustrated in Figure 1.

Figure 1. Bit patterns for a T1 signal.

Description

When the DS1 signal emerges from a T1 interface device, it passes through a transformer and is injected onto the T1 line with alternating pulses whose amplitudes typically alternate between +3 V and –3 V about midway down the T1 line. The rising and falling edge slew rate can be as fast as 0.6 V/ns at the driving end.

Applications for T1 lines are quite varied. Within a telecom switch, the T1 line is a popular low-cost transmission medium for wiring from the switch fabric to the outer switch boundary. As a transmission medium on a digital loop carrier (DLC), a T1 line can connect 24 customers on a subscriber loop to a main telecom switch installation, thus saving a bundle of tip/ring pairs. In an ISDN application, a T1 line can carry 23 bearer channels and one data channel to implement the ISDN primary rate interface (PRI), i.e., 23 B+1D.

In a telecom switch installation, there is often the need to switch T1 lines. One such application includes T1 sparing, such as found in protection switching. Until now, this switching was done with large, bulky, electromechanical relays, which were susceptible to shock, vibration, contact wear, contact bounce, sticking, and long-term reliability failures. Also, in switching, an electromechanical relay creates substantial contact noise and relay coil kickback. Furthermore, these relays tend to require significant amounts of coil current, neighboring in the mid tens of milliamps. Since they require full coil voltage to operate, no sharing of coil currents is possible for multiple-switching situations, unless one chooses to run the coils from a central office battery voltage. More importantly, modern equipment installations are migrating to full surface-mount manufacturing, for which these large relays are unsuitable.

The LH1514 solid state relay overcomes the above limitations of electromechanical relays in an 8-pin, surface-mount DPST configuration (it is also available in a through-hole DIP). The LH1514 is rugged, very small, and offers superior reliability at 20 FITs (failures in 109 device-hours). It offers smooth, quiet switching and 8 mA guaranteed control over the entire temperature range, and, perhaps best of all, it is available in a surface-mount package for reduced manufacturing costs. Additionally, the LED turn-on voltage is less than 1.5 V, allowing ganged switches to share control currents by placing the LEDs in series. This saves substantial power in dense T1 relay matrices.

The LH1514 is targeted primarily for DS1 switching applications, being optimized for low on-resistance (5 Ω, typical) and good off-state blocking. For a slew-rate of 0.6 V/ns, the LH1514 will allow no more than 100 mV of signal bleed-through. The useful frequency range of the LH1514 is not limited by data rate but by the slew rate of the signal being blocked in the off-state. DS1A, DS1C, and DS2 data rates could be switched by the LH1514 if the off-state bleed-through of 100 mV max at 0.6 V/ns is adequately low.

In this document, the LH1514 T1 Relay from Vishay will be described. Next, a typical application will be presented, including extensive design information. Basic T1 transmission principles, as they relate to the LH1514, will be discussed, including the following:

- Off-state Bleed-through
- Transmission Line Matching
- Return Loss Minimization
- Impact of Mismatch on Meeting the DS1 Template
- Lightning Survival
- Interoffice Application of the LH1514

Main Characteristics of the LH1514 [3]

The LH1514 is manufactured in High-Voltage BCDMOS process, using optical coupling to achieve 3750 V isolation from input to output. BCDMOS features dielectric isolation (DI) in order to achieve the ultimate in component isolation. The DI is essential for optically coupled devices, such as a solid state relay. The relay chip is activated by an infrared LED mounted in close proximity. DI prevents unwanted device interaction between light-sensitive devices and the active output circuitry. The BCDMOS process has been in production since 1984 and is presently in its third generation.

Figure 2 illustrates the pinout for the LH1514.

The LH1514 consists of two normally off poles (2 form A, DPST). With no LED current, both poles are off. When the LED is activated with sufficient forward current, the two poles will turn-on so that they meet the on-state specifications. The key specifications for the LH1514 are given in the Absolute Maximum Ratings and Electrical Characteristics sections.

Because the ON-resistance of the solid state relay cannot be made ideally zero, some care must be taken to ensure proper line matching on the receiving end of the T1 line when the LH1514 is employed.

The off-state bleed-through is a critical specification. That and the ON-resistance are the most important parameters. ON-resistance and off-state blocking will be discussed in the following sections.
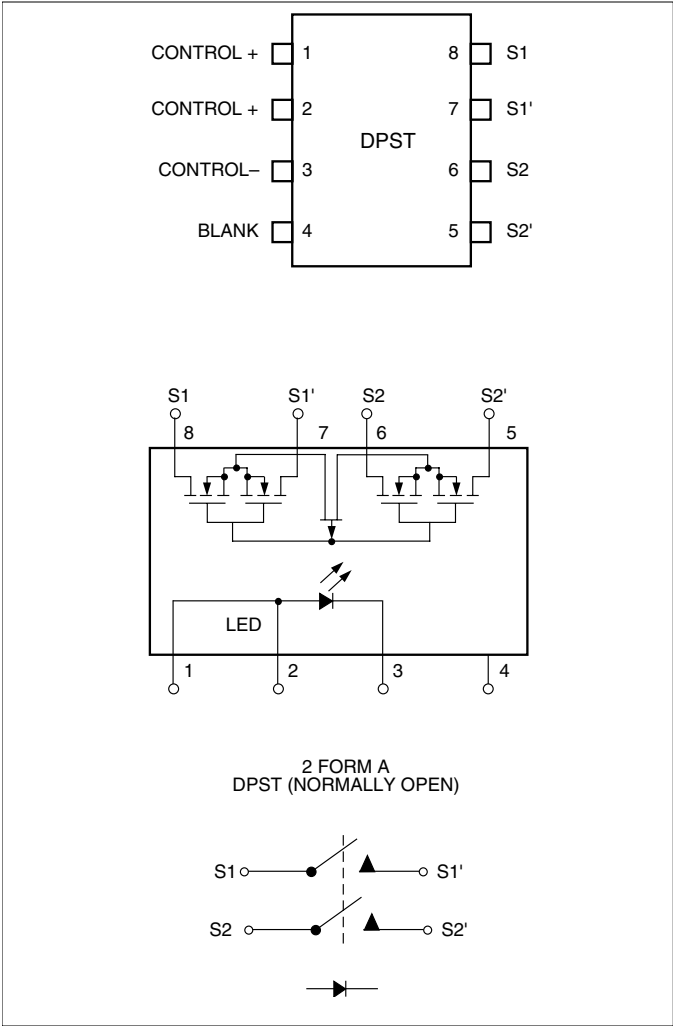
Figure 2. Pinout for the LH1514

Table 1. Absolute maximum ratings

Parameter	Symbol	Value	Unit
Ambient Temperature Range	T_A	–40 to +85	°C
Input/Output Isolation Voltage	V_{ISO}	3750	V_{RMS}
LED Continuous Forward Current	I_F	50	mA
dc or Peak ac Load Voltage	V_L	15	V
Continuous dc Load Current	I_L	150	mA
Power Dissipation	Pdiss	600	mW

Table 2. General electrical characteristics

Parameter	Min	Typ	Max	Units
LED Forward Current Required for Turn-on:				
T=25°C	—	2.5	4.0	mA
T=85°C	—	5.0	8.0	mA
R_{ON} (25°C)	3.0	5.0	8.0	Ω
TC(R_{ON}) (–25°C to +85°C)	—	–0.0936	—	%/°C
Vmax (breakdown voltage @ 50 µa)	15	25	—	V
$T_{ON/OFF}$	—	0.5	1.0	ms
Off-state Bleed-through, 1.5 MHz Square Wave, 3 V_{pp}, T_{RISE}=5 ns, 50 Ω Load (See Figure 3)	—	70	100	mV pk

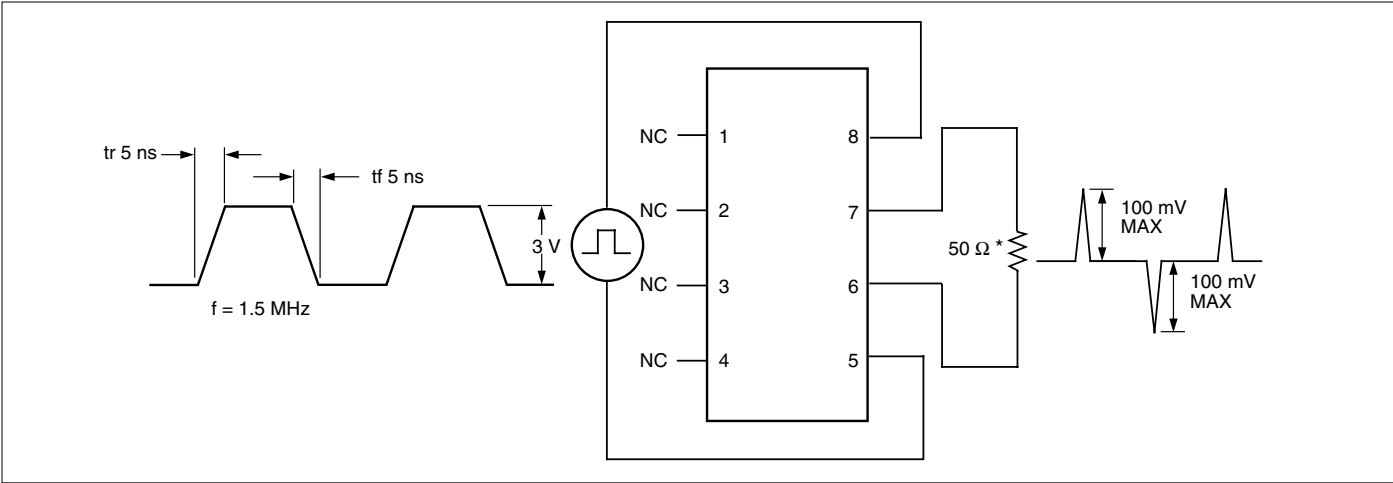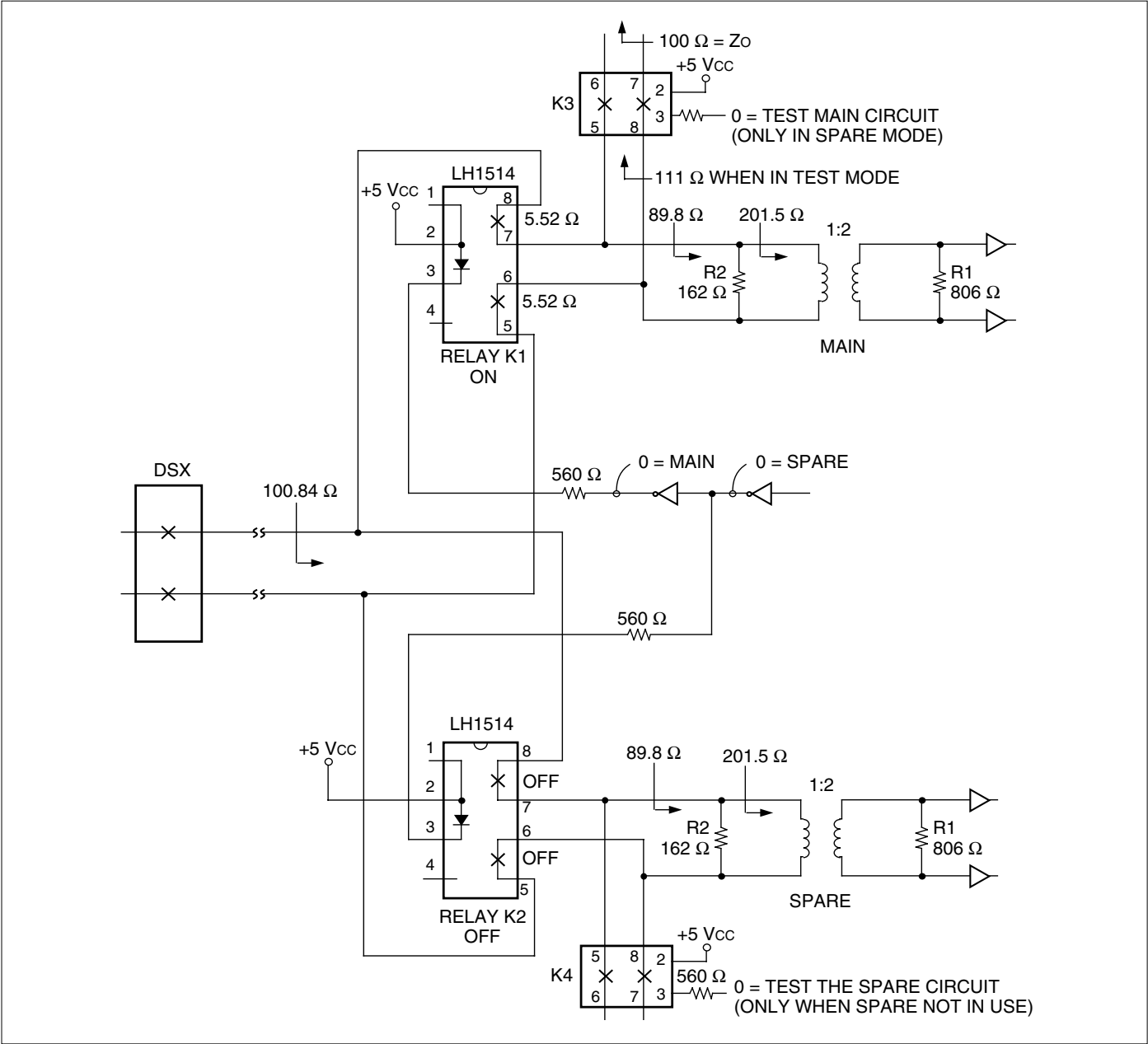**Figure 3. Off-state bleed-through for the LH1514**

Figure 4. Typical T1 relay application

A T1 Relay Application

Figure 4 illustrates a typical application for the LH1514. It is a T1 sparing application where a T1 line could connect to one of two receiving-end circuits. This application is often known as **protection switching**.

As illustrated in Figure 4, the upper relay, K1, is on, while the lower relay, K2, is off. When K1 is off and K2 is activated, the network is said to be in a **protection switching** mode. In this mode, the main receiving circuitry is placed under testing while the signal is routed to a spare receiver. When not in a **protection switching** mode, the spare receiver is under test. The LED current, provided through a TTL inverter, is set at 8 mA to ensure full operation over the temperature range of 0°C to 75°C for this example.

The signal comes from a digital cross connect (DSX). The DSX is that place in a system where T1 lines are hardwired together. It also serves as a good place to measure and characterize signals. The DSX is typically midway between the source and load points, which, in turn, are typically several hundred feet from one another.

The transmission line is typically 22-gauge twisted pair, offering about 0.47 dB of attenuation per every 100 ft. at 1 MHz. At 2 MHz, 3 MHz, and 4 MHz, the attenuation is about 0.66 dB, 0.82 dB, and 0.94 dB per 100 ft., respectively [1,4].

The 100 Ω transmission line arrives at the load through an LH1514. The signal then arrives at a padding resistor, R2, continues across a step-up isolation transformer, and finally crosses a load resistor, R1, before it arrives at the receiving-end circuitry.

At room temperature, the R_{ON} of the LH1514 is typically 5 Ω per pole. But over temperature, the minimum R_{ON} would be 2.86 Ω at 75°C. ($TC(R_{ON})$=–0.0936%/°C). Thus, the R_{ON} ranges from 2.86 Ω (min, hot) to 8.19 Ω (max, cold), having a midrange value of 5.52 Ω ±2.67 Ω for this set of conditions. The loading on the receive end of the relay is purposely made a little lower than 100 Ω. R1 and R2 are selected to work with the R_{ON} of the relay, in order to provide nominal 100 Ω matching to the transmission line. The terminating impedance seen by the transmission line is given by:

$$ZT = 2 \cdot R_{ON} + (R2 \| (R1 / N^{**}2)) \qquad (1)$$

where:

R_{ON} is the R_{ON} of one relay pole, nominally 5.52 Ω for this case. R1 is chosen to be nominally 806 Ω (using standard 1% values). R2 is chosen to be nominally 162 Ω. N is the effective transformer turns ratio, 2 for this case, and ZT is the terminating impedance seen by the transmission line, which turns out to be 100.84 Ω for this set of component values. This provides nearly perfect 100 Ω matching for the transmission line.

The off-state blocking becomes important in the protection switching mode. Here, the main receiver under test cannot be corrupted by the signal now going to the spare. Likewise, the signal going to the spare cannot corrupt the main receiver now under test. It is important to prevent false triggering of the digital circuitry on the receiving end. The LH1514 has been designed to provide no more than 100 mV of false signaling on the transformer primary due to off-state bleed-through.

The worst-case signal dv/dt (i.e., slew-rate) has been estimated at 0.6 V/ns. This dv/dt will try to induce signal current to jump across the off-state relay contacts due to their off-state capacitance. To the off-state relay, there is 49.6 Ω of loading. This consists of the 89.8 Ω loading, looking into the transformer, in parallel with the T1 line coming in through the test path when relay K3 is on. The impedance looking into K3 when it is on is 111 Ω. This path includes the 100 Ω transmission line impedance, plus the 5.52 Ω midrange on-resistance per pole of the LH1514. The resultant 49.6 Ω loading to the off-state relay is where the 50 Ω load in Figure 3 comes from.

An important feature of the LH1514 is its inherent ability to prevent off-state bleed-through. Figure 2 shows a JFET suspended between the midpoints of the two relay contacts. This patent pending technique uses the JFET to absorb unwanted signals that want to jump across the off-state relay contacts. Conceptually, it is a balanced version of the T-switch topology. When the relay contacts are on, the JFET is deactivated.
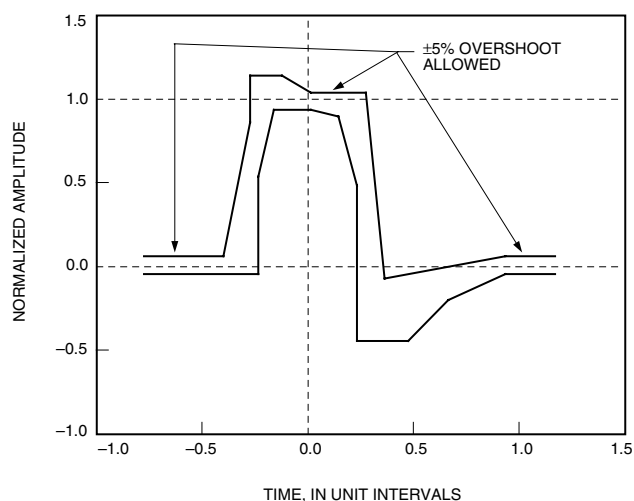
Note:

> It is very important to use the same relay package to switch both leads in a twisted pair in order to minimize crosstalk and to take best advantage of this low bleed-through feature. Relay contacts should not be mixed and matched indiscriminately with different signals in the same package.

As stated above, the loading network on the receive end forms 100.84 Ω matching in conjunction with the two 5.5 Ω poles. This suppresses unwanted reflections from arriving back at the DSX. There is good reason for this.

Bellcore has published requirements for T1 lines [1]. Hard requirements for things like load mismatch and return loss are not well defined in reference [1], due to lack of industry convergence. While many important spec are listed as typical, the allowable waveform distortion at the DSX is very well defined. This specification is referred to as the DSX template. Load mismatch and return loss can be inferred from it. The template for DS1 waveforms is illustrated in Figure 5.

Figure 5. Conformance requirements for the DS1 waveform [1]

Minimum Curve		Maximum Curve	
Time in Unit Intervals	Normalized Amplitude	Time in Unit Intervals	Normalized Amplitude
–0.77	–0.05	–0.77	0.05
–0.23	–0.05	–0.39	0.05
–0.23	0.5	–0.27	0.8
–0.15	0.95	–0.27	1.15
0.0	0.95	–0.12	1.15
0.15	0.9	0.0	1.05
0.23	0.5	0.27	1.05
0.23	–0.45	0.35	–0.07
0.46	–0.45	00.93	0.05
0.66	–0.2	1.16	0.05
0.93	–0.05		
1.15	–0.05		

It is customary for a system engineer to use an oscilloscope probe at the DSX to analyze the waveform. A transparency-photocopy of the DSX template is often taped to the screen of an oscilloscope to check for conformance. Because the boundaries of the DSX template are based on relative values, any reasonable manipulation can be done on the screen to bring the waveform into the template. This includes varying the horizontal time/division and vertical volts/division. Inverting the pattern of the screen is also used for negative pulses. One purpose of the template is to ensure that there is no crosstalk between bundled T1 lines.

This works on two bases:

- A pulse conforming to the waveform will not have so much overshoot that it causes crosstalk.

- If a signal conforms to the template, it is ensured that whatever crosstalk is present, it will not cause false triggering of the digital detection circuitry on the receiving end. Fortunately, crosstalk is usually very, very low.

Two (2) portions of the template require variation of less than 5% of peak value in the pulse shape:

- The baseline trace just before the rising edge and after the falling edge undershoot window.

- The flattened portion of the template, at the top, just past the overshoot window.

For a 3 V peak amplitude, this allows for only 150 mV of variation, which will consist of line reflections, crosstalk, and other secondary phenomena.

The shape of the template provides some insight into what to expect in T1 transmission medium. Over the distance of the transmission line, some attenuation of high-frequency components in the squared pulse is to be expected. This will result in rounding of the corners on the waveform. In order to maintain signal integrity, the rising and falling edges of the pulse are typically predistorted with some overshoot, with the intent of providing a more squared pulse at the receiving end. The driving-end circuitry often include some amplitude and wave shape programming to account for varying line lengths. One technique for tailoring the line drive is to use L-C equalization networks to create the desired predistortion. Integrated devices such as the T7289[2] form Vishay provide programmable equalization to accommodate long lines and overshoot predistortion simultaneously.

Relating the Template to Line Matching

In this section, it will be shown that use of the LH1514 allows for conformance to the DSX template, even though this relay has a nonzero R_{ON}.

The following analysis should be performed for any T1 transmission system, regardless of whether or not a solid state relay is used. The following analysis may seem complicated at first, but it is actually quite easy and gives enormous insight into the performance of your system.

The worst-case 5% waveform variation allowed by the DSX template, as mentioned above, relates directly to return-loss and line matching. Return loss is simply a measure of how much signal is lost in return from the load side of a line back to the driving side. It is a figure of merit for matching the load to the transmission line. For example, infinite return loss implies that matching is perfect; the transmitted energy is fully absorbed by the load, and no reflection occurs. The definition of return loss is:

$$RL = 20 \cdot log | (ZT + Z0) / (ZT - Z) | \qquad (2)$$

where:

RL is return loss in dB.
Z0 is the transmission line characteristic impedance.
ZT is the terminating impedance.

If, for example, Z0 is 100 Ω and ZT is 95 Ω, the return loss will be 31.8 dB. RL specs of 26 dB minimum are common.

Note that if Z0=ZT, perfect transmission line matching occurs, and there is no reflection back to the load. The result is infinite return loss.

However, if ZT equals zero or infinity, the return loss is zero, and the energy impinging on the receiving end will be fully reflected back into the direction of the driver.

For the circuit in Figure 4, the return loss is nominally 47.57 dB, which is quite good. We will soon analyze how this varies with normal component tolerances.

(Transmission line matching is not to be confused with maximum power transfer matching. In maximum power transfer matching, it is desirable to have ZT as the complex conjugate of the transmission line impedance, perceived at the load, in order to maximize the power transferred to the load. In transmission line matching, it is desirable to have ZT be precisely equal to Z0, in order to reduce reflections. Since Z0 in this case has a real component of 100 Ω, matching is greatly simplified.)

The reflected voltage is related to return loss and is given by:

$$Vr = [(ZT - Z0) / (ZT + Z0)] \cdot Vpulse \qquad (3)$$

where:

Vr is the peak amplitude reflected signal.
Vpulse is the amplitude of the incoming signal.

If, for example, Z0 is 100 Ω and ZT is 95 Ω, the amount of signal reflection is 2.56% of Vpulse. This means that from a 3 V pulse, 77 mV will be reflected back into the direction of the source. If this 77 mV peak happens to appear at the DSX, the waveform observed there will have this 77 mV blip riding on top of the desired signal. It is a harmless phenomena, but it shows up nevertheless.

An excellent estimate of signal reflection can be made as follows: the percentage of reflected signal is approximately half the percentage of load mismatch. In this example, a 5% mismatch caused approximately a 2.5% reflection.

If this reflection nudges a portion of the waveform out of the DSX template, a system technician can observe it in the field. Even though this reflected signal has absolutely no impact on system performance, the technician can take note of it. In most cases, such phenomena are not a concern. But every reasonable effort should be made to provide good matching at the receiving end of the T1 line.

When analyzing the case of the solid state relay in the sparing application, the SSR ON-resistance must be counted as part of the load. Based on equation (3), the reflection coefficient, G, is given by:

$$Vr/Vpulse = G = (A - 1)/(A + 1) \qquad (4)$$

where:

G is the reflection coefficient

and

$$A = ZT/Z0 \qquad (5)$$

Perfect matching would make G equal to zero and **A** equal to unity. For the circuit in Figure 4, **A** is 1.0084 and G is 4.18e–3. It is desirable to keep the absolute value of G under 0.05, based on the DSX template requirement discussed above. This means that **A**, the ratio of ZT to Z0, must be kept in the following range:

$$0.9047 < A < 1.1053 \qquad (6)$$

As long as **A** is kept in this range, |G| will be 0.05 or less and the DSX template requirements will be met.

In this analysis, we will carefully look at all the variables which contribute to **A** and confirm that the DSX template requirements are fulfilled. It is important to note that this analysis should be done for every T1 application, regardless of whether a solid state relay is used.

When more than two variables are present, it is more realistic to use a statistical rms approach to the worstcase analysis, rather than lay all of the possible worstcase extremes end-to-end. This is a more reasonable approach to the worst-case problem because of the statistical nature of the variations being dealt with. It is highly unlikely that all of the worst-case conditions would precisely combine in the worst of all ways. In this type of analysis, the variational contributions to **A** are individually squared and added, and then the square root of the sum is taken to yield the final variation.

First we find **A** as a function of all the component values in Figure 4.

Combining equations (1) with (5):

$$A = \frac{R1 \cdot R2 + 2 \cdot R1 \cdot R_{ON} + 2 \cdot R_{ON} \cdot R2 \cdot N^2}{Z0 \cdot (R1 + R2 \cdot N^2)} \qquad (7)$$

Since **A** is not a linear function of Z0, Z1, Z2, N, and R_{ON}, and because the variations under consideration are small compared to Z0, the calculus will be used to find the variation of **A** as a function of these variables. Once this is done, the following deviations from nominal **A** are found:

$$d(A) = \frac{-A}{Z0} \cdot dZ0 \qquad (8)$$

$$d(A) = \frac{(R2 \cdot N)^2}{Z0 \cdot H^2} \cdot dR1 \qquad (9)$$

$$d(A) = \frac{R1^2}{Z0 \cdot H^2} \cdot dR2 \qquad (10)$$

$$d(A) = \frac{2}{Z0} \cdot dR_{ON} \qquad (11)$$

$$d(A) = \frac{-2 \cdot N \cdot R1 \cdot R2^2}{Z0 \cdot H^2} \cdot dN \qquad (12)$$

where:

$$H = R1 + R2 \cdot N^2 \qquad (13)$$

and:

d(**A**) is the variation in **A**.
dZ0 is a variation in Z0.
dR1 is a variation in R1.
dR2 is a variation in R2.
dR_{ON} is a variation in R_{ON}.
dN is a variation in the effective turns ratio, N.

It is interesting in the above expressions to note the minus signs in front of a few of them. These give indication as to how the variables interact. For instance, an increase in Z0 would cause **A** to decrease, but an increase in R_{ON} will tend to cancel that effect.

To find the worst-case variation using an rms analysis, every term for d(**A**) given above is squared and then the sum of these squares is raised to the 1/2 power.

Obtaining values for equations (8) – (13) is rather straightforward. Most parameters are assigned their nominal value. Transmission line impedance is typically controlled within 5%. The midrange value for R of 5.52 Ω is used. Variation in R1 and R2 is taken to be 2.5% of nominal value. This comes from the fact that end-of-life limits for a 1% resistor can go as far as 2.5% from center over device lifetime. The effective turns ratio can be very well controlled, typically 2%.

The following values are used in quantifying equations (8) –13):

Z0 = 100 Ω
dZ0 = ±5 Ω, max

R1 = 806 Ω
dR1 = ±20.15 Ω, max

R2 = 162 Ω
dR2 = ±4.05 Ω, max

R_{ON} = 5.52 Ω
dR_{ON} = ±2.67 Ω, max

N = 2
dN = ±0.04, max

Based on the above, the individual variations in d($\mathbf{A}$) are as follows:

d($\mathbf{A}$)[dZ0] = ±5.042e–2
d($\mathbf{A}$)[dR1] = ±1.00054e–2
d($\mathbf{A}$)[dR2] = ±1.2445e–2
d($\mathbf{A}$)[dR$_{ON}$] = ±5.34e–2
d($\mathbf{A}$)[dN] = ±1.60087e–2

By squaring the above terms, adding their squares, and taking the root of that, the worst-case variation in $\mathbf{A}$ is the following:

d($\mathbf{A}$)max = ±7.684e–2

So, $\mathbf{A}$, which is typically 1.0084, varies between 0.9316 and 1.0852, which conforms to the limits defined in equation (6).

Based on equation (4), the nominal reflection coefficient, G, is 4.18e–3. This means the return loss is typically 47.57 dB, which is very good. Based on the variation in $\mathbf{A}$, G varies between –3.54e–2 and +4.09e–2. This means the return loss will range to as low as 27.77 dB.

Considering these results, the worst-case wiggle in the waveform at the DSX, due to mismatch reflections, will be 4.09%, against a specification of 5%. Other contributors to this number might be identified, but their contribution is believed to be less than that of the parameters discussed, so their contribution to the rms total would be slight.

There is one factor which provides free margin against the template with regard to load reflections. The line attenuation per foot will reduce the pulse as it travels from the DSX to the load. So, the reflected signal is a small replica of an attenuated DSX pulse. Furthermore, by the time it arrives back to the DSX as a reflection, it is attenuated even further. Assuming that the distance from DSX to load is about 100 ft., the attenuation at 1 MHz is 0.47 dB/100 ft. x 200 ft., or 0.94 dB. So for this 100 ft. situation, the worst-case wiggle at the DSX due to mismatch reflections is just 89.7% of what was calculated above, or just 3.67% against a specification of 5%.

This analysis is easier than it might look at first. It has been found, interestingly, that many existing installations have never been analyzed from the standpoint of worst-case mismatch and its impact on the template requirements. Regardless of whether or not you use a solid state relay, an analysis similar to the one described above should be done for your system at all points where there is a receiving-end load to be designed. If you are using the LH1514, you will find that the benefits of using a solid state relay will make the analysis time well worth the effort, in addition to gaining insight into your design.

A final concern might be how the system can function properly if the ON-resistance of the solid state relay will provide some attenuation of the incoming signal. In the example just illustrated, the worst-case attenuation would be about 2 dB, and is typically 1 dB (i.e., [89.8/[100.84]=1.0 dB). It turns out that T1 driving circuitry usually has substantial signal punch in excess of that required. Furthermore, the receiving end is usually quite sensitive. Using a commercially available transformer [2] provides a minimum of a 2.4 V peak at the DSX when programmed for a 665 ft. stretch to the DSX. That signal continues down the T1 line, and then is stepped up 1:2 at the receiver end. The receiver sensitivity is at least 0.85 V peak. Assuming the distance from the DSX to the receiver is another 665 ft., the line attenuation will be 665 ft. x 0.47 dB/100 ft.= 3.1 dB. The excess drive under worst-case is then:

Excess Drive = 20 x log [2.4 x 2/.85] – 3.1 dB
Excess Drive = 11.94 dB

This will more than compensate for the 1 dB–2 dB loss due to the solid state relay ON-resistance.

Impact of On-State Pole-to-Pole Capacitance on Line Matching

The 50 pF on-state pole-to-pole capacitance of the LH1514 should be considered when analyzing the load match to the transmission line. In practice, the 50 pF of pole-to-pole capacitance will present a capacitive reactive element in parallel with the 100 Ω load. This will cause mismatch reflections at the higher-frequency components of the incoming pulse.

Computer simulation has shown that the reflection will appear as a very narrow spike traveling back to the generating end. Yet in a system installation, no such reflection can be observed. According to computer simulation, for a 50 pF of pole-to-pole capacitance, and a 0.3 V/ns dv/dt, this spike will be about 15 ns wide and about 1.5 V tall, riding on top of a 3 V DS1 pulse. But it does not show up in a practical DS1 application because it is swallowed up by losses and reactive characteristics of the transmission line at high frequencies (characteristics which are not modeled by most SPICE simulators).

For example, this 15 ns wide spike may be viewed for the moment as correlating to 66 MHz signal. The highest frequency at which T1 line losses are published is 10 MHz. There the losses are 16 dB for 1000 ft.[1]. Beyond 9 MHz the loss/1000 ft. increases dramatically and is difficult to extrapolate. A conservative extrapolation would yield a loss of at least 60 dB at 60 MHz. Thus, what would be a 1.5 V, 15 ns spike reflected back on a lossless line will show up in practice as something in the tens of millivolts range for 22-gauge twisted-pair. This will have no impact on the template requirements for DS1 and DS1A applications. At higher data rates such as DS2 (6.312 Mbits/s), the 50 pF should be considered more closely as the reactance of the 50 pF at this frequency approaches the value of Z0.

Lightning Survival

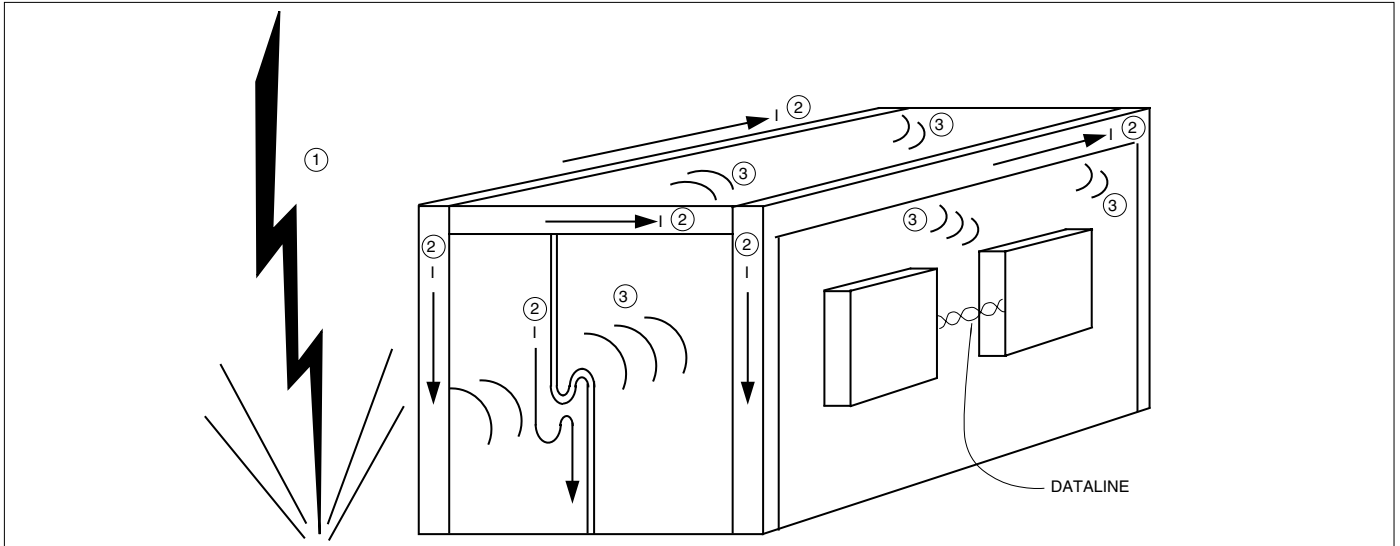In this section, it will be shown that the LH1514 survives lightning quite well.

The first point to remember about lightning is that no one expects a data line in a telecom switch to survive a direct lightning hit. The destructive force of a lightning hit is just too great to be handled by mere circuit techniques. Besides, if a direct lightning strike is experienced, fire and structural damage to the premises will be a much bigger problem than the digital system damage.

A more practical concern is the energy induced onto a data line by means of a nearby lightning strike. There are two applicable situations: in-building wiring and out-of-building wiring.

For in-building wiring, the following sequence of events occurs (this sequence is illustrate in Figure 6):

1. Lightning strikes on or near the building.

2. Massive current surges are momentarily induced in the metallic elements of the building (pipes steel l-beams in the frame, etc.).

3. These, in turn, reradiate their energy onto twisted-pair data line running point-to-point within the system.

Figure 6. Qualitative model for lightning surges on data lines confined within premises
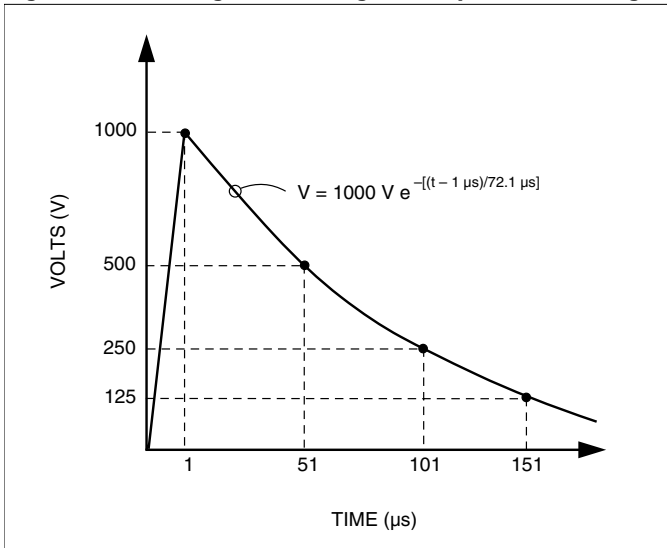

DATALINE

US-ISDN-BRI, ANSI T1.605 describes the requirements for in-building data lines which run up to 1 km (3286 ft.) in length. It is interpreted in another document for the benefit of end-users. *North American ISDN Users Forum, Document ICOT-90-40.* The key requirement for this discussion center around a lightning surge which must be applied to all lines longitudinally (i.e, all lines simultaneously, or common-mode). The applied surge follows the shape given is Figure 7.

Figure 7 describes a voltage ramp climbing to 1000 V in 1 ms and decaying to 500 V in 50 µs. The source is limited with a 31.6 Ω resistor in series with every line. Thus, the maximum current allowable during the surge is 31.6 A.
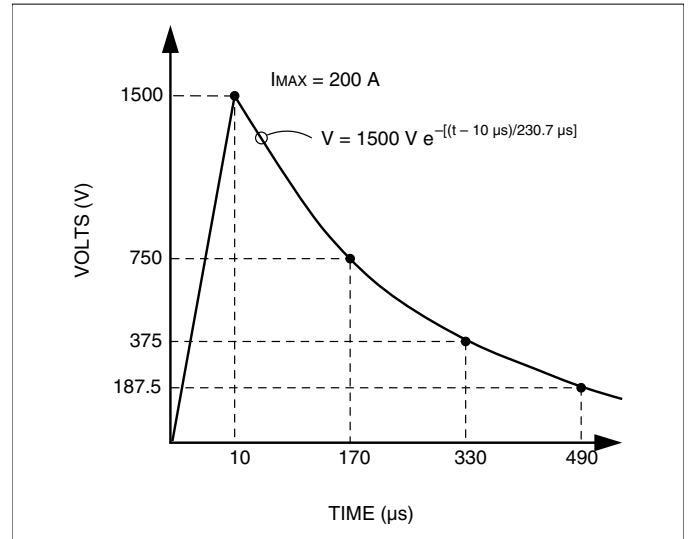
For out-of-building lines, the duration of the surge is longer. The lightning strikes near the twisted pair and induces energy right onto it. Out-of-building lightning would be a concern, for example, in a digital loop carrier (DLC) application where T1 lines bring telephone service to a remote community. Even though the T1 bundle is typically shielded, induced lightning is still a concern.

Figure 7. ANSI longitudinal surge for in-premises wiring

$$V = 1000\ V\ e^{-[(t - 1\ \mu s)/72.1\ \mu s]}$$

VOLTS (V): 1000, 500, 250, 125
TIME (µs): 1, 51, 101, 151

Surge requirements for out-of-building wiring is described in FCC part 68.302. These lightning surge models were originally developed with tip/ring pairs in mind. It would stand to reason that since tip/ring conductors are in close proximity to one another, the induced voltage would be identical for both of them, and, thus, there should be no need for metallic (differential) surge testing. But in practice, tip/ring lines are very often surge protected with crowbar devices such as SCRs and gas discharge tubes. In the event that one protector fires before the other (or perhaps one protector does not fire at all), there will be a perceived metallic surge on the tip/ring pair. This series of events will never occur, however for most T1

Figure 8. FCC 68.302 longitudinal surge for out-of-building lines, "10x160"

I_{MAX} = 200 A

$$V = 1500\ V\ e^{-[(t - 10\ \mu s)/230.7\ \mu s]}$$

VOLTS (V): 1500, 750, 375, 187.5
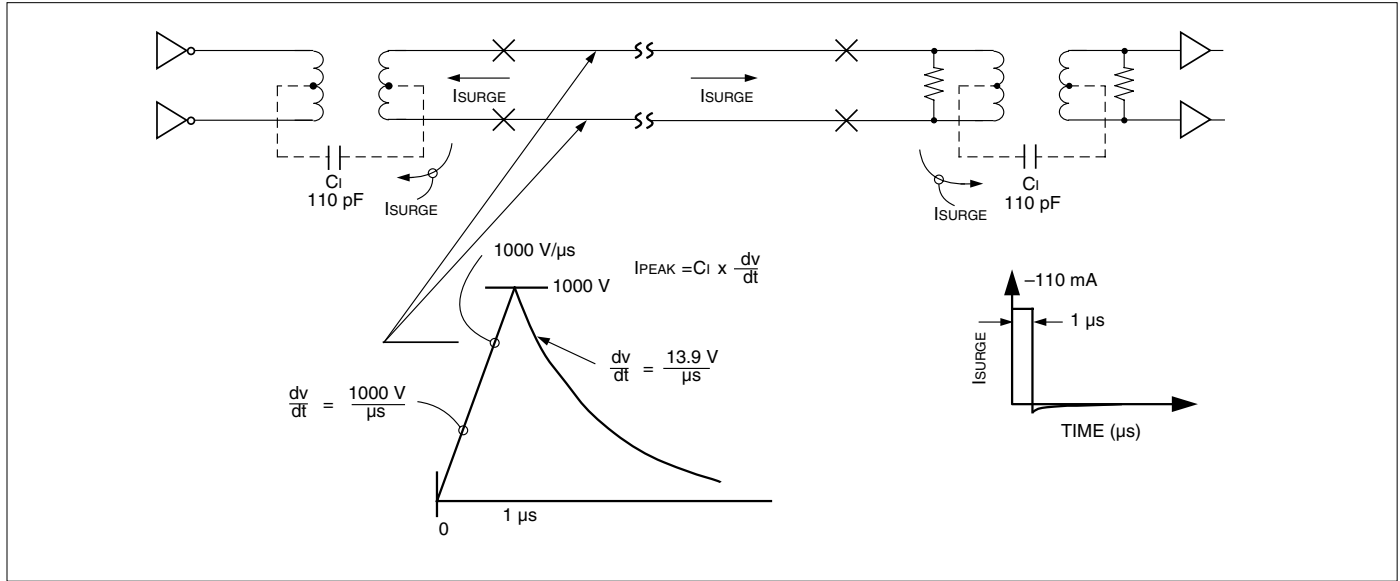TIME (µs): 10, 170, 330, 490

lines. T1 lines have no lightning protection circuitry on them, except for isolation transformers provided on both the receiving and transmitting ends.

Thus, metallic surges have no bearing on the lightning survival issue for T1 out-of-building wiring, unless they are required by regulatory agencies or if active protection devices are used on the line, as discussed above. In this case, the

metallic surges would be applicable, and the LH1514 would not be recommended. However, even without a solid state relay, it would be catastrophic for most T1 installations to be subjected to a metallic surge.

Figure 9. Lightning model for a T1 line under surge typical application circuit)

Therefore, in most cases, it is sufficient for T1 lines to be evaluated under longitudinal surges. The out-of-building longitudinal surge from FCC 68.302 is illustrated in Figure 8.

In Figure 8, the expression "10x160" refers to the 10 µs rise time of the surge, and the 160 µs fall time it takes for the voltage to reach half of its peak value.

Figure 9 illustrates the circuit dynamics of an induced lightning strike. Note the absence of any protection devices on the balanced transmission line, except for the isolation transformers.

Referring to Figure 9, the surge comes upon the T1 relay in the following way. First, a surge is induced onto the data line. The induced energy has no dc return path to ground, thanks to the isolation transformers. The interwinding capacitance provides a 110 pF transient path to ground through the transmit and receive devices. The worst-case surge current is given by:

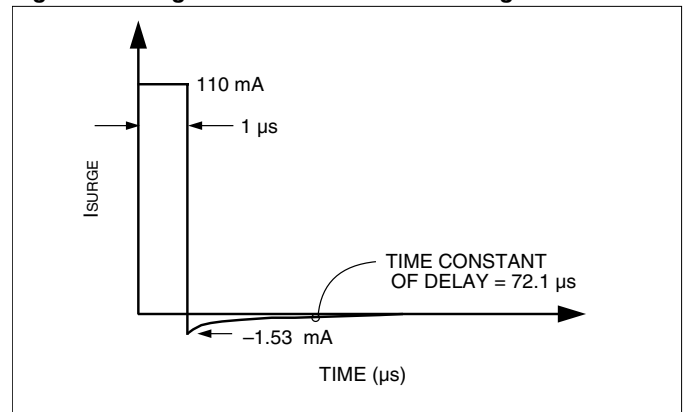$$Isurge = Ci^* dv/dt \qquad (14)$$

where:

C_i is the interwinding capacitance of the isolation transformer, dv/dt is the slop of the incoming surge.

A commercially available transformer with an interwinding capacitance of approximately 110 pF was chosen for this example because it has the highest interwinding capacitance of any T1 transformer. They typically range from 5 pF to 90 pF. The worst-case dv/dt is from the ANSI-BRI spec, which from Figure 7 is 1000 V/µs. The out-of-building FCC surge does not present a worst-case dv/dt. Therefore, we have used the ANSI-BRI surge for this analysis. Thus, the maximum possible surge is 110 mA. It would follow the shape shown in Figure 10.

The LH1514 can handle this 110 mA peak surge with no problems whatsoever. If the LH1514 is in breakdown (i.e., in the off-state), it can easily handle 300 mA steady state. Typical devices will degrade at about 500 mA of breakdown. In the on-state, the LH1514 is even more rugged.

This means that the LH1514 can be used with confidence both for in-building and out-of-building applications, as long as transformer isolation is used.

Figure 10. Surge current for the circuit of figure 9

Conclusion

The LH1514 solid state relay for T1 signals has been presented, with extensive design information. Recent trends towards improved reliability and ease of manufacture make the LH1514 attractive for both new designs and redesigns. It offers clean, bounce-free switching, ruggedness, and high reliability in a small, surface-mount package, lending itself well to improved performance and reduced manufacturing costs. A careful analysis of load matching, and its impact on the DSX template, has been presented. An analysis such as this is called for regardless of whether or not an SSR is used. Lightning survival was reviewed illustrating that T1 lines are normally susceptible only to longitudinal surges. The T1 driver/receiver circuitry is protected by isolation transformers, which also help protect the LH1514 by eliminating any return path to ground.

The growing T1 equipment market will benefit from the features of this new device.