

## Cross Talk Analysis

Many previous analyses of twisted-pair transmission systems have assumed that the distribution of cross talk noise is Gaussian. These have yielded reasonably accurate predictions of system bit error rates. However, in applying the error rate analysis, there is an implicit assumption that the cross talk noise is independent of the data on the disturbed system. This is often the case in telecommunication systems, but is not always the case in LANs, where the disturbing links are those on which the disturbed data is being retransmitted. For example, the NEXT interfering with data received at one port of a hub is a result of the retransmission of earlier bits of the same data on other ports. If the cross talk noise is of sufficient amplitude to cause an error in the received data, this error is extremely likely to be repeated every time the same data is transmitted. If a packet is errored by cross talk, that particular packet is likely always to be errored.

To guarantee the error-free transmission of any packet, the worst-case peak cross talk voltage must be found. The peak cross talk noise from multiple disturbers can be calculated directly from a knowledge of the cross talk channels and the disturbing data source. The NEXT and FEXT cross talk channel frequency responses can be calculated for any pair combination using measurements of the pair-to-pair NEXT or FEXT loss. Once the cross talk channel frequency response is known, it is possible to find the impulse response of this channel by inverse Fourier transform. We define the impulse response of the NEXT channel as:

$$g_n(t) = F^{-1}(H_n(f))$$

and the impulse response of the FEXT channel as:

$$g_r(t) = F^{-1}(H_r(f))$$

To find the cross talk noise voltage at the receiver decision point,  $n(t)$ , caused by any data pattern  $f(t)$ , the impulse response is convolved with  $f(t)$ :

$$n(t) = f(t) \star g(t), \quad (1)$$

where  $g(t)$  represents either  $g_r(t)$  or  $g_n(t)$  as appropriate. Our goal is to find the worst-case cross talk for any data pattern, so  $n(t)$  must be calculated for all values of  $f(t)$ . It is therefore useful to apply some limit to the duration of  $f(t)$  to shorten the computation time, and this can be done by taking into consideration the finite duration of the cross talk channel impulse response. A typical impulse response of a NEXT channel is shown in Fig. 1. The duration of the cross talk impulse response is typically less than 1400 ns, which is equivalent to 42 symbol periods for the 30-megabaud transmission rate used in quartet signaling. Therefore, the cross talk waveform during the last six symbols of a pattern  $f(t)$  can be predicted accurately if the duration of  $f(t)$  is restricted to 1600 ns.

The cross talk for any  $f(t)$  is calculated as follows. The disturbing data source is assumed to be the output of a 5B/6B block coding function and consists of eight sequential six-bit codewords, each chosen from an alphabet of 32 codewords. The total number of permutations that  $f(t)$  can take is therefore  $32^8$ . For each permutation,  $n(t)$  is computed according to equation 1. The peak cross talk noise voltage generated by any value of  $f(t)$  can then be found by searching each resultant  $n(t)$ .

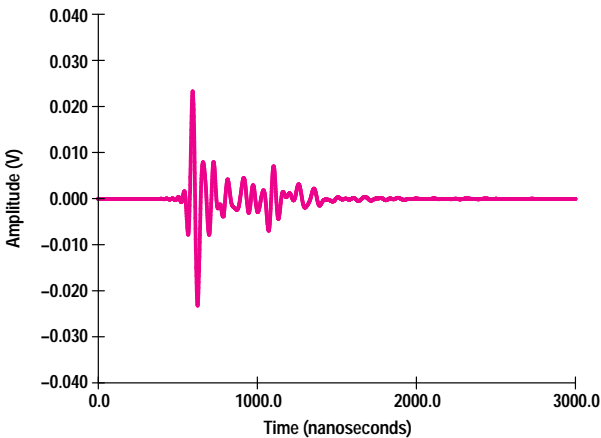


Fig. 1. Typical impulse response of a NEXT channel.

The peak cross talk noise voltage, which represents the maximum noise generated by a worst-case data pattern, can be calculated in this way for each pair combination in a 25-pair cable by repeating the search described above using the NEXT or FEXT loss particular to that pair combination. For each pair combination, the maximum cross talk noise voltage is recorded. The distribution for a typical cable is shown in Fig. 2 for NEXT and FEXT. (The cross talk noise voltage is normalized to the signal amplitude at the receiver decision point.) We denote the maximum NEXT noise voltage for pair  $i$  disturbing pair  $k$  as  $v_{pk,NEXT}^{i,k}$  and the maximum FEXT noise voltage due to pair  $i$  disturbing pair  $k$  as  $v_{pk,FEXT}^{i,k}$ .

### Multiple-Disturber Cross Talk

The worst-case cross talk environment for UTP PMDs operating over 25-pair bundles consists of three far-end disturbers and four near-end disturbers. Modeling this environment is relatively straightforward given the distributions of  $v_{pk,NEXT}^{i,k}$  and  $v_{pk,FEXT}^{i,k}$ . For each choice of disturbed pair ( $k$ ), four NEXT disturbers ( $a,b,c,d$ ) and three FEXT disturbers ( $p,q,r$ ), the total noise voltage for multiple disturbers is:

$$v_{pk,total} = \sum_{i=a,b,c,d} v_{pk,NEXT}^{i,k} + \sum_{j=p,q,r} v_{pk,FEXT}^{j,k}$$

By calculating the multiple disturber noise voltage in this way we assume, pessimistically, that the maximum noise voltages for the worst-case disturbing patterns from each disturbing source occur at the same time and with the same polarity on the disturbed pair  $k$ . This is obviously a worst-case scenario.

A Monte-Carlo approach has been used to choose combinations ( $k,a,b,c,d,p,q,r$ ) randomly from the 25 pairs of a cable. For each choice,  $v_{pk,total}$  was calculated. The resulting distribution of  $v_{pk,total}$  is shown in Fig. 2. The maximum multiple-disturber cross talk noise expected on any pair of the cable for any choice of disturbing pairs can be estimated from the higher extreme of this distribution (such as the first percentile). This number represents the noise voltage for the worst-case choice of disturbing and disturbed pairs, with the maximum noise contributions from all disturbing pairs occurring simultaneously on the disturbed pair. For the example shown, the first percentile of the total peak noise distribution is 47% of the signal. This allows a substantial margin for error-free signal detection.

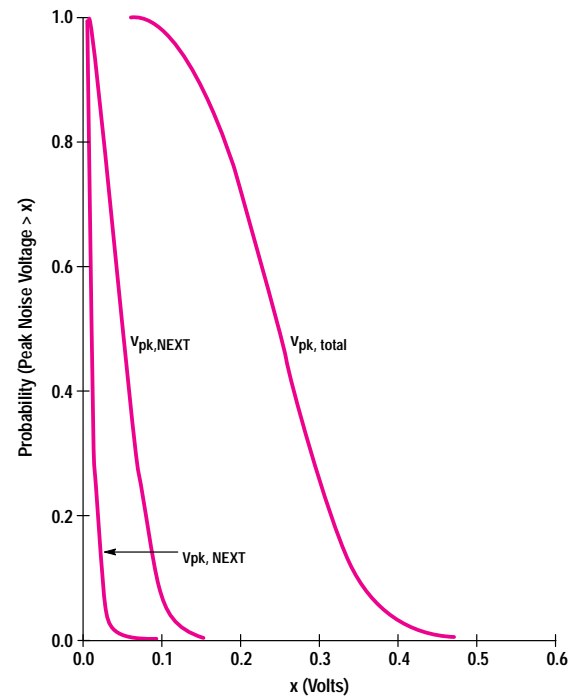


Fig. 2. Distribution of  $v_{pk,FEXT}^{i,k}$ ,  $v_{pk,NEXT}^{i,k}$ , and  $v_{pk,total}$  for a typical 25-pair cable.