H.264/MPEG-4 AVC Video Compression Tutorial

Introduction

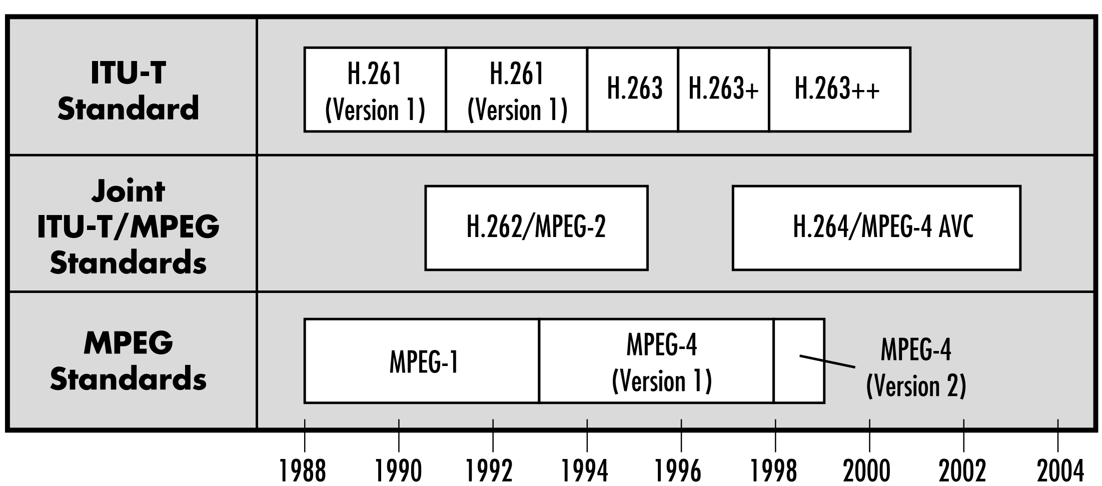
The upcoming H.264/MPEG-4 AVC video compression standard promises a significant improvement over all previous video compression standards. In terms of coding efficiency, the new standard is expected to provide at least 2x compression improvement over the best previous standards and substantial perceptual quality improvements over both MPEG-2 and MPEG-4.

The standard, being jointly developed by ITU-T and ISO/IEC, will address the full range of video applications including low bit-rate wireless applications, standard-definition and high-definition broadcast television, video streaming over the Internet, delivery of high-definition DVD content, and the highest quality video for digital cinema applications.

The ITU-T name for the standard is H.264 (previously called H.26L), while the ISO/IEC name is MPEG-4 Advanced Video Coding (AVC) which will become Part 10 of the MPEG-4 standard. Since AVC is an extension to the current MPEG-4 standard, it will benefit from MPEG-4's well-developed infrastructure tools (e.g. system layer and audio). It is expected that MPEG-4 AVC will be selected over the current MPEG-4 video compression standard, known as MPEG-4 Advanced Simple Profile (ASP), for the majority of applications that demand the highest compression and quality levels.

As can be seen in the diagram "History of Video Standards", the ITU-T and ISO/IEC are responsible for all previous international video compression standards. To date, the most successful of these standards has been MPEG-2, which has gone on to achieve mass-market acceptance in areas such as DVD, digital television broadcast (over cable and satellite), and digital set-top box. The new H.264/MPEG-4 AVC standard represents the single largest improvement in coding efficiency and quality since the introduction of MPEG-2. Consequently, over time, it is expected that H.264/MPEG-4 AVC will displace MPEG-2 and MPEG-4 ASP in many existing applications, in addition to opening up several new markets (e.g. video over ADSL).

History of Video Standards



Order Number XXXXXXXX
January 2003

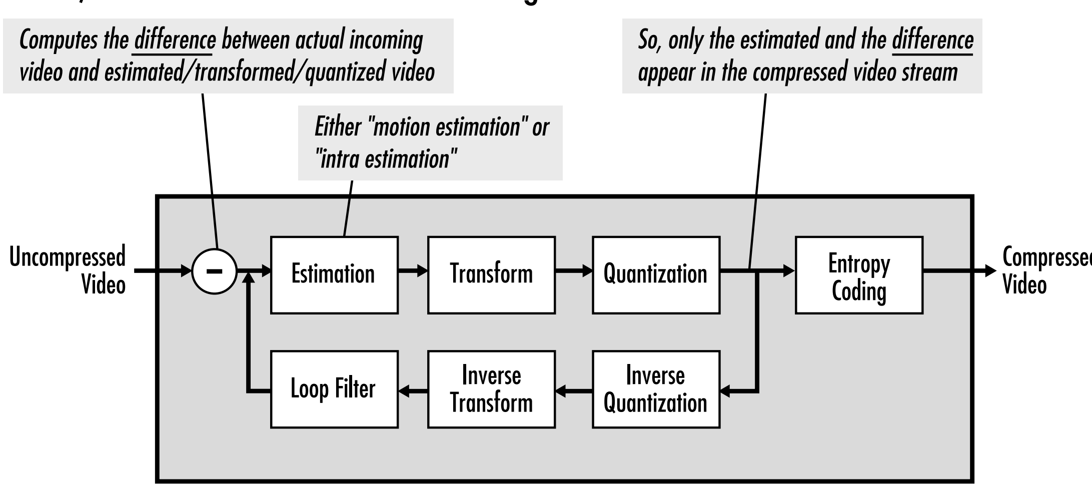
Technical Overview

As can be seen in the "H.264/MPEG-4 AVC – Overview Block Diagram", the new standard is composed of several processing stages:

- Motion Estimation and Intra Estimation
- Transform (and Inverse Transform)
- Quantization (and Inverse Quantization)
- Loop Filter
- Entropy Coding

Video is composed of a stream of individual pictures that can be broken down into individual blocks of 16 pixels by 16 lines called "macroblocks". This practice simplifies the processing which needs to be done at each stage in the compression algorithm. For example, a picture from a video stream at standard definition resolution (720x480) is divided into 1,350 (45x30) macroblocks. It is at the macroblock level that further processing takes place. We will explore the purpose and function of each of these processing elements in the next few sections.

H.264/MPEG-4 AVC – Overview Block Diagram

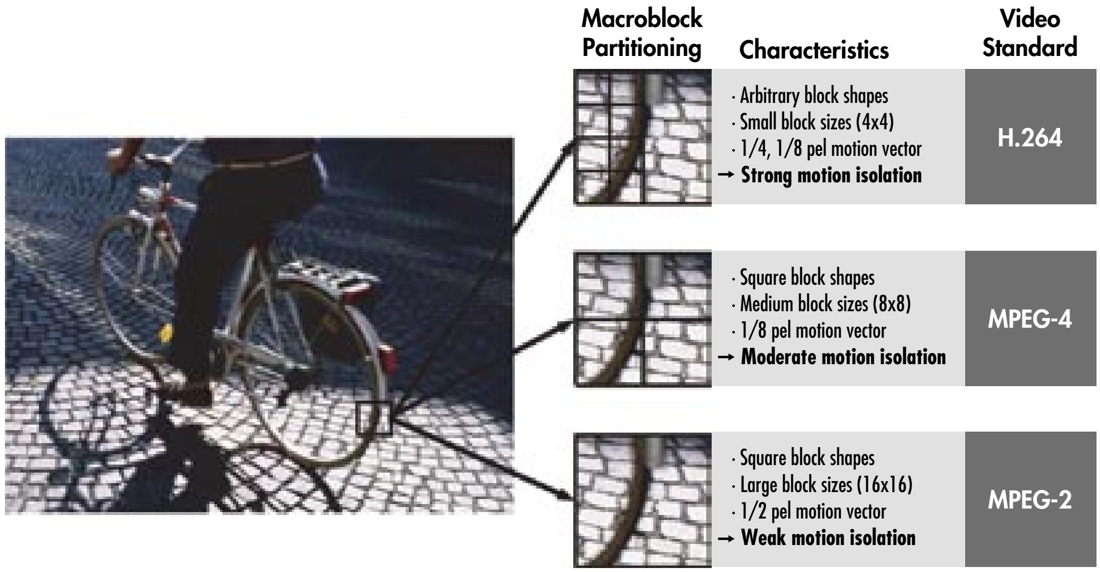


Technical Overview

Motion estimation is used to identify and eliminate the temporal redundancies that exist between individual pictures. When searching for motion relative to a previous picture, the picture to be encoded is called a "P-picture". When searching both within a previous picture and a future picture, the picture to be encoded is called a "B-picture".

To improve coding efficiency, the macroblock is broken down into smaller blocks that attempt to contain and isolate the motion as shown in the diagram "H.264 Motion Estimation – Superior Motion Estimation". Then, motion vectors to previous and/or future pictures are used to predict a given block. H.264/MPEG-4 AVC introduces smaller block sizes, greater flexibility in block shapes, and greater precision in motion vectors.

H.264 Motion Estimation – Superior Motion Estimation

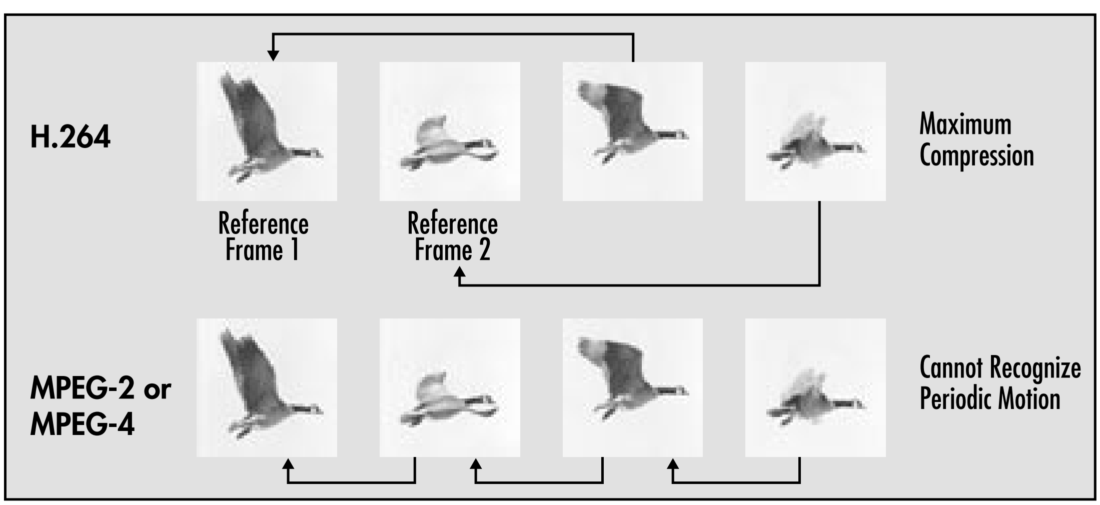


In addition, H.264 introduces the concept of multiple reference frames. This feature is useful for dealing with:

1) Motion that is periodic in nature
2) Translating motion and occlusions
3) Alternating camera angles that switch back and forth between two different scenes

An example of periodic motion is shown in "H.264 Motion Estimation – Multiple Reference Frames".

H.264 Motion Estimation – Multiple Reference Frames

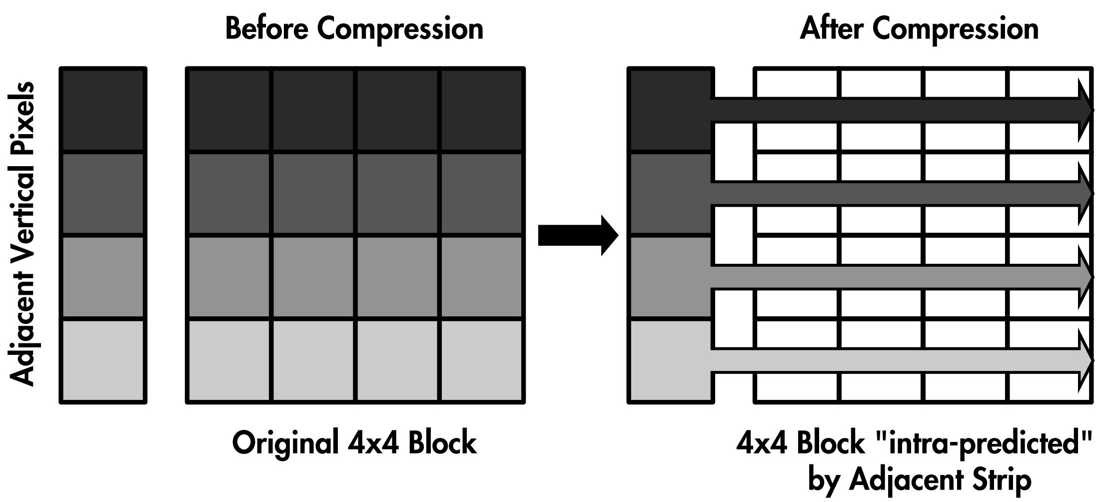


The difference between the predicted block and the actual block is then coded, which results in far fewer bits than if only the original block was coded.

Intra Estimation

In instances where motion estimation cannot be exploited, intra estimation is used to eliminate spatial redundancies. Intra estimation attempts to predict the current block by extrapolating the neighboring pixels from adjacent blocks in a defined set of different directions. The difference between the predicted block and the actual block is then coded. This approach, unique to H.264/MPEG-4 AVC, is particularly useful in flat backgrounds where spatial redundancies often exist. An example of this is shown in "H.264 Intra Estimation".

H.264 – Intra Estimation



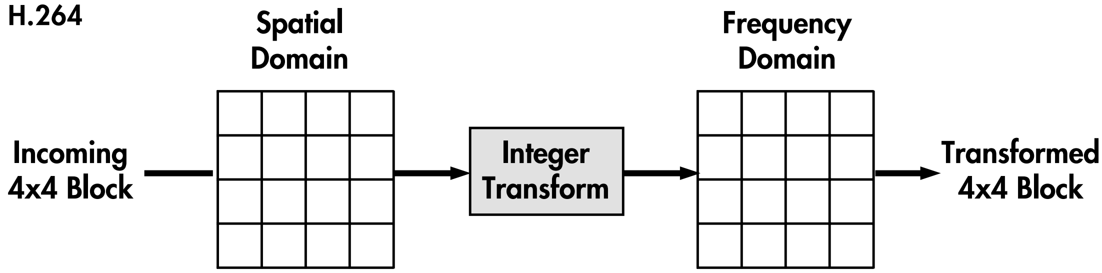
Transform

Results from the motion estimation or intra estimation stages are transformed from the spatial domain into the frequency domain. H.264/MPEG-4 AVC uses a DCT-like 4x4 integer transform. In contrast, MPEG-2 and MPEG-4 ASP employ a true DCT 8x8 transform that operates on floating-point coefficients.

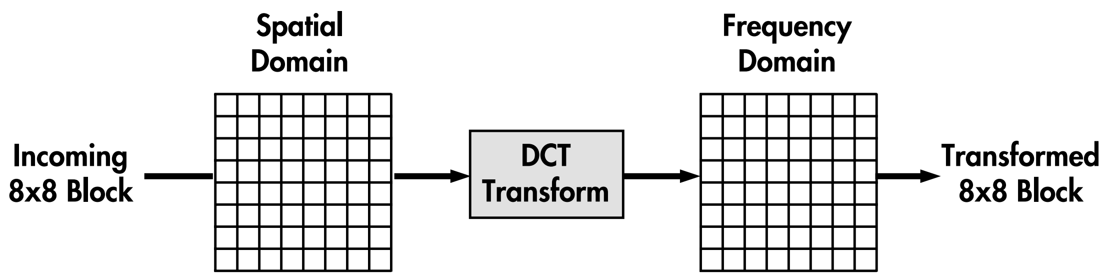
The smaller block size of H.264/MPEG-4 AVC reduces blocking and ringing artifacts. Integer coefficients eliminate rounding errors inherent with floating point coefficients and that cause drifting artifacts with MPEG-2 and MPEG-4.

H.264 Transform

H.264



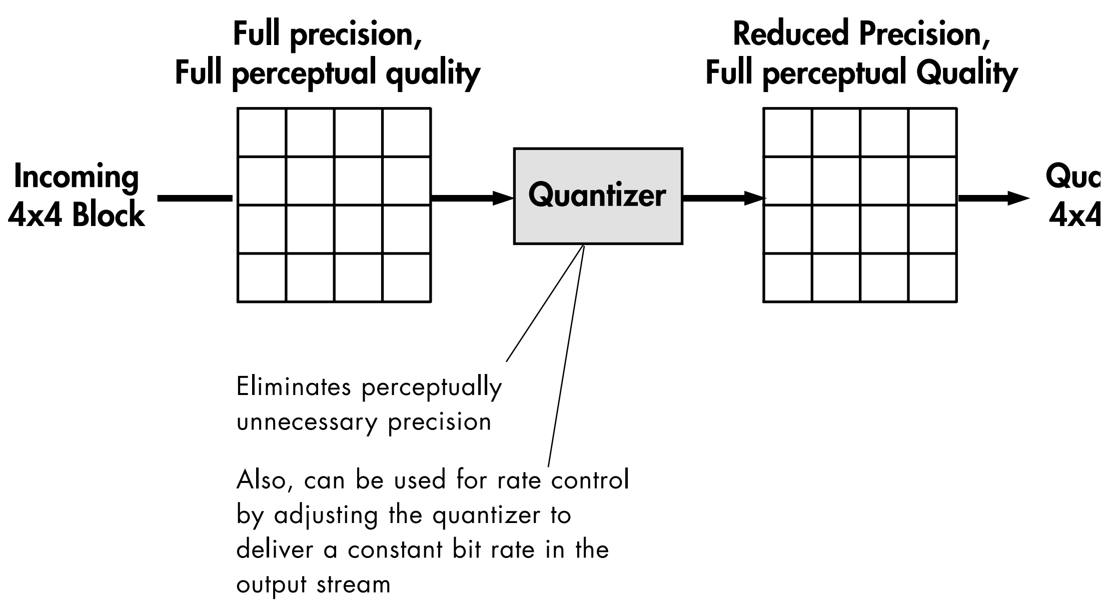
MPEG-2 / MPEG-4



Quantization

The coefficients from the transform stage are quantized, which reduces the overall precision of the integer coefficients and tends to eliminate high frequency coefficients, while maintaining perceptual quality. The quantizer is also used for constant bit rate applications where it is varied to control the output bit rate.

H.264 Quantization / Rate Control



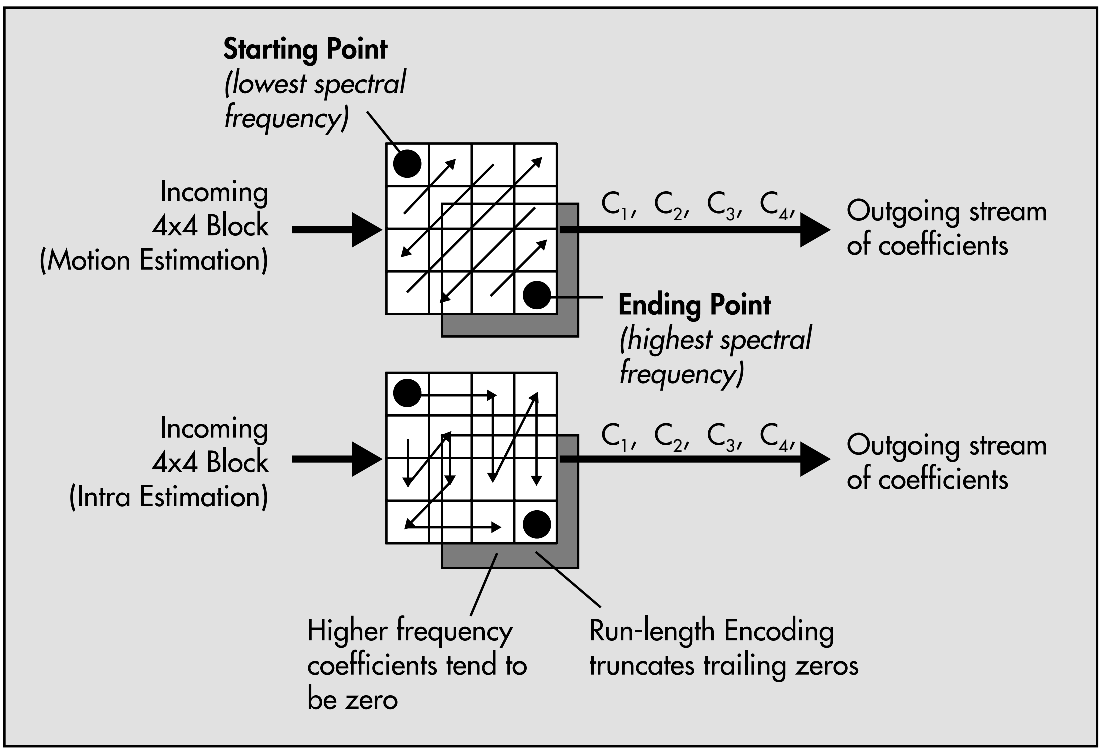
Loop Filter

The H.264/MPEG-4 AVC standard defines a de-blocking filter that operates on both 16x16 macroblocks and 4x4 block boundaries. In the case of macroblocks, the filter is intended to remove artifacts that may result from adjacent macroblocks having different estimation types (e.g. motion vs. intra estimation), and/or different quantizer scale. In the case of blocks, the filter is intended to remove artifacts that may be caused by transform/quantization and from motion vector differences between adjacent blocks. The loop filter typically modifies the two pixels on either side of the macroblock/block boundary using a content adaptive non-linear filter.

Entropy Coding

Before entropy coding can take place, the 4x4 quantized coefficients must be serialized. Depending on whether these coefficients were originally motion estimated or intra estimated, a different scan pattern is selected to create the serialized stream. The scan pattern orders the coefficients from low frequency to high frequency. Then, since higher frequency quantized coefficients tend to be zero, run-length encoding is used to group trailing zeros, resulting in more efficient entropy coding.

H.264 Entropy Coding – Serialization of Coefficients



The entropy coding stage maps symbols representing motion vectors, quantized coefficients, and macroblock headers into actual bits. Entropy coding improves coding efficiency by assigning a smaller number of bits to frequently used symbols and a greater number of bits to less frequently used symbols.

The following table summarizes the two major types of entropy coding: Variable Length Coding (VLC) and Context Adaptive Binary Arithmetic Coding (CABAC). CABAC offers superior coding efficiency over VLC by adapting to the changing probability distribution of symbols, by exploiting correlation between symbols, and by adaptively exploiting bit correlations using arithmetic coding. H.264 also supports Context Adaptive Variable Length Coding (CAVLC) which offers superior entropy coding over VLC without the full cost of CABAC.

H.264 Entropy Coding – Comparison of Approaches

Characteristics	Variable Length Coding (VLC)	Context Adaptive Binary Arithmetic Coding(CABAC)
• Where it is used	MPEG-2, MPEG-4 ASP	H.264/MPEG-4 AVC (high efficiency option)
• Probability distribution	**Static** - Probabilities never change	**Adaptive** - Adjusts probabilities based on actual data
• Leverages correlation between symbols	**No** - Conditional probabilities ignored	**Yes** - Exploits symbol correlations by using "contexts"
• Non-integer code words	**No** - Low coding efficiency forhigh probability symbols	**Yes** - Exploits "arithmetic coding" which generates non-integer code words for higher efficiency

Conclusion

The new H.264/MPEG-4 AVC offers significant bit rate and quality advantages over all previous standards. The standard is expected to be ratified by ISO in early- to mid-2003. Initial products based on the standard are available now.

H.264/MPEG-4 AVC Video Compression Tutorial

Sales Offices and Design Resource Centers

LSI Logic Corporation
Corporate Headquarters
Milpitas, CA 95035
Tel: 408.433.8000

USA

Arizona
Tempe
Tel: 480.921.3305

Colorado
Boulder
Tel: 303.448.7700

Illinois
Oakbrook Terrace
Tel: 630.954.2234

Louisiana
Hammond
Tel: 985.542.1115

Maryland
Columbia
Tel: 410.992.0200

Laurel
Tel: 301.362.0232

Massachusetts
Waltham
Tel: 781.890.0180

Minnesota
Minneapolis
Tel: 952.921.8300

Oregon
Beaverton
Tel: 503.521.9601

Pennsylvania
Hatboro
Tel: 215.957.0600

Texas
Arlington
Tel: 817.695.8000

Austin
Tel: 512.794.9006

Houston
Tel: 281.376.2000

Utah
Salt Lake City
Tel: 801.264.8050

Washington
Kirkland
Tel: 425.889.8443

CANADA

Ontario
Kanata
Tel: 613.592.1263

Alberta
Calgary
Tel: 403.207.5526

INTERNATIONAL

Europe
United Kingdom
Phone: 44-1344-426544

China
Beijing
Phone: 86-10-6263-8296

Chengdu
Phone: 86-28-667-8831

Japan
Tokyo
Tel: 81-3-5463-7821

Korea
Seoul
Phone: 82-2-528-3400

Taiwan
Taipei
Phone: 886-2-2718-7828

To receive product literature, visit us at http://www.lsilogic.com.

Printed in USA
Doc. No. I22001