Tutorial

Margin Testing of Digital Videotape Recorders

By Richard D. Petit

The recently emerging use of digital recording techniques in the video field has bridged the gap between broadcast and instrumentation applications of magnetic storage. The differing demands of data and video storage require specific error-correction and testing strategies. This article presents a historical perspective of testing in the instrumentation and computer storage fields. The increase in recording densities with the attendant need for margin testing is discussed. Margin testing is defined and the application of margin-testing techniques for the DVTR is proposed.

Magnetic storage system test techniques have evolved with the advancing technology of recording itself. Prior to the emergence of digital, and later wideband, applications, flutter and signal-to-noise ratio measurements were generally sufficient. With the advent of early data processing recorders came jitter and bit-error rate measurements, while wideband recorders benefited from such sophistication as group delay measurements. Color video recording, with its dependence upon phase relationships, led to vectorscope phase measurements.

Tests have emerged to fit the sensitivities of the end application of the recorder. Early audio recorders were tested to meet the needs of the human ear (a fairly discriminating sensor). Digital recorders had to withstand the rigors of the banking sector (also discriminating). The complexities of video recording notwithstanding, the most direct judge of performance is the human eye. Flutter measurements of an audio recorder relate directly to human perception, while phase relationships in a video recorder are more arcane. To this end the results as observed on a video monitor have held importance in the video field.

Recent developments in both the audio and video fields have tended to blur the distinctions between these and other previously diverse applications of recording technology. Not only have these two analog media yielded to digital encoding, computer data storage recorders, traditionally conservative, have given way to higher recording densities. Powerful error-detection and correction schemes (EDAC), as well as error concealment, have evolved to enhance the performance of these recorders, but traditional recorder problems persist. The more these problems are understood and minimized, the more effective the EDAC strategies will be.

Digital Recording Considerations

The relative immunity of digital recording to nonlinearities in the record/reproduce process has led to higher accuracies, greater stability, and more dynamic range than FM and direct recording.[1] This, coupled with ongoing advances in attainable digital recording densities, the chief distractor when compared with analog techniques, has led to its widespread application. However, with the exception of digital audio, most of the applications have involved high data rates, thereby renewing the importance of such parameters as bandwidth, jitter, tape imperfections, and signal-to-noise ratio.

Bandwidth considerations have led to a variety of digital recording formats. Upper band edge, DC content, and self-clocking capability have played competing roles in choosing the appropriate format. Bi-phase formats are self-clocking and do not require any DC response but need an upper band equal to the data rate. The Miller format, also called MFM or delay modulation, reduces the band edge needs to one-half the data rate but requires data transition integrity to within 25% of a bit cell. Nonreturn-to-zero (NRZ) formats benefit from one-half data rate band edge and 50% bit cell transition integrity requirements, but need DC response. Strategies to minimize the need for DC response such as randomizing and

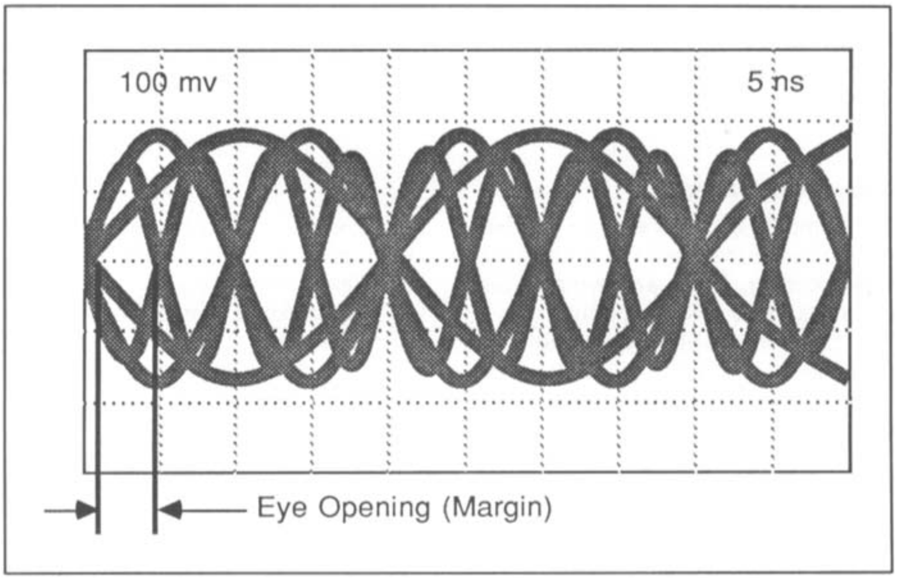

Figure 1. Eye pattern.

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group encoding exist, but one way or another, limiting recorder bandwidths must be considered.

Jitter, predominently caused by head-to-tape motion irregularities; tape imperfections, leading to dropouts; and noise, in its many personifications, all affect the integrity of digital recording. These and other detractors all combine to impact error rate. Indeed, of all considerations, error rate is the final judge of the performance of a digital recorder, yet it remains sudden and unpredictable. While the measurement of the individual detractors each yield insight to margin, an overall margin measurement would be useful.

Margin Testing

Historically, the need for margin testing has been partially fulfilled by the use of eye patterns. An eye pattern can be obtained on an oscilloscope by synchronizing to the data and displaying several bit periods. Typically this is done by looking at a point in the reproduction channel where the data is still analog in nature and yields a pattern similar to that shown in Fig. 1. Influences detracting from margin have the effect of blurring the pattern. Margin is inferred from the width of the openings in the eye patterns.

While eye patterns reveal the cumulative effect of all error causes and are simple to create, they are difficult to quantify and subjective by their very nature.[2,3,4] In the disk drive industry, which is faced with similar challenges to the tape arena, window sliding[5,6] has long been in use as a test technique. This approach involves artificially modifying the window of acceptibility and measuring error rates. If a narrow window yields acceptable results, a degree of margin is inferred. More recently, the use of time interval analysis (TIA) has been advocated.[3,4,6,7] Time interval analysis evaluates the channel under test without modifying the expected performance characteristics of the channel.

As a means of introduction to time interval analysis, consider the following. A square wave has a half period, T, as depicted in Fig. 2a. In the absence of any abnormalities, each half period is exactly equal to T in length. If many of these periods (T) were measured with the results stored in memory, a picture, or histogram, could be plotted against time.

Figure 2b represents such a plot. In this case, since all measured intervals were exactly T, the result is a straight line. The height of the line corresponds to the number of measurements (in this case about 30,000). The horizontal placement of the line corresponds to the time between edges on the measured waveform.

Figures 3a and 3b are the same as the two previous figures except that jitter has been added to the signal. The TIA plot reveals the presence of square wave jitter as a distribution of measured time intervals around the nominal expected period, T. The width of the plot at the baseline is the magnitude of peak-to-peak jitter.

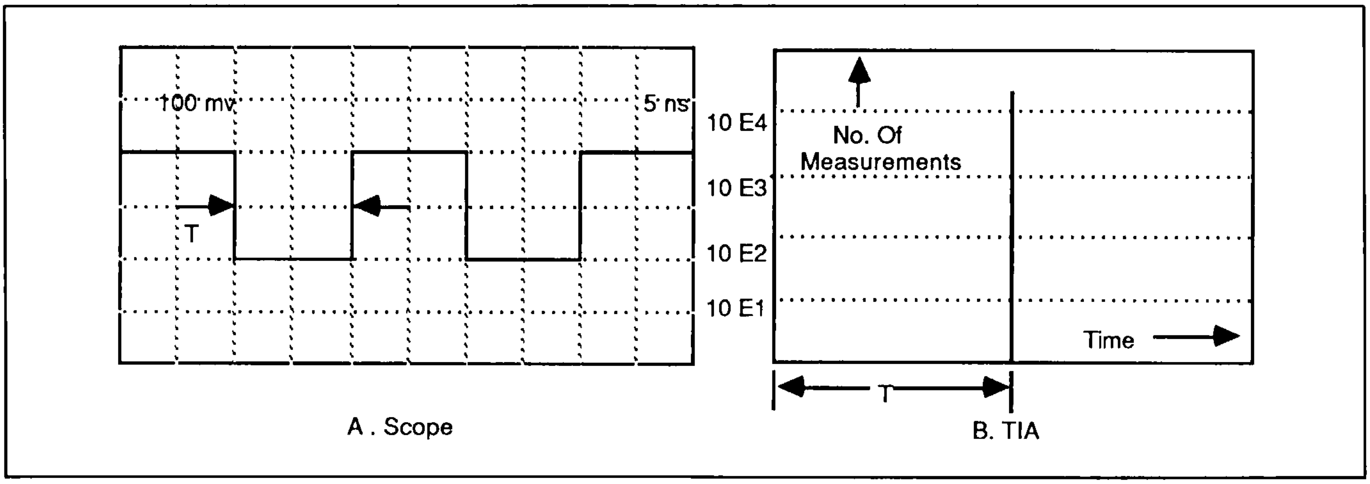


Figure 2. Square wave without jitter: (a) scope; (b) time interval analysis (TIA).

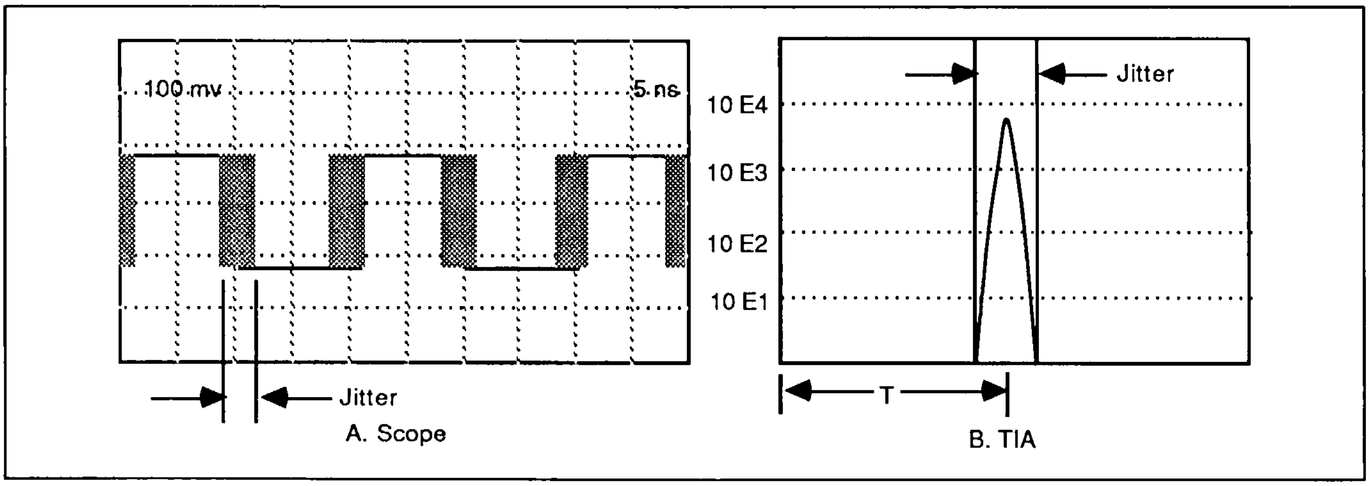


Figure 3. Square wave with jitter: (a) scope; (b) TIA.

Figure 4 illustrates this measurement technique applied to a Miller, or MFM, encoded digital signal. An ideal signal is shown. A salient characteristic of MFM is that the time between transitions is limited to one of three possibilities. These are shown in Fig. 4 as *T*1, *T*2, and *T*3. For random data content, the number of occurrences at each of these intervals should be nearly equal. Figure 4b depicts this case from a measurement sample of 100,000 intervals. There are about 33,000 occurrences at precisely each of the three nominal periods.

A realistic view of reproduced MFM data would yield TIA histograms similar to those shown in Fig. 5. Figure 5a shows the results of jitter, itself due, in part, to system noise and head-to-tape motion irregularities. Figure 5b depicts the added degradation due to bit shift, in turn due to intersymbol interference. As discussed earlier, these and other factors detract from margin in an additive way.

The literature abounds with discussions of these problems as well as others and the relative merits of the various encoding schemes. Common to all the problems and the various solutions is the need for a consistent and quantitative technique for the measurement of margins. Figure 6, a Miller[2] TIA histogram, illustrates how time interval analysis can combine the tests performed by eye pattern and sliding window analysis. The spacing between adjacent interval distributions, measured at the baseline, is equivalent to the opening in an eye pattern. The margin window, depicted as a shaded bar under the expected distribution of each of the five possible time intervals, is the equivalent of a sliding window.

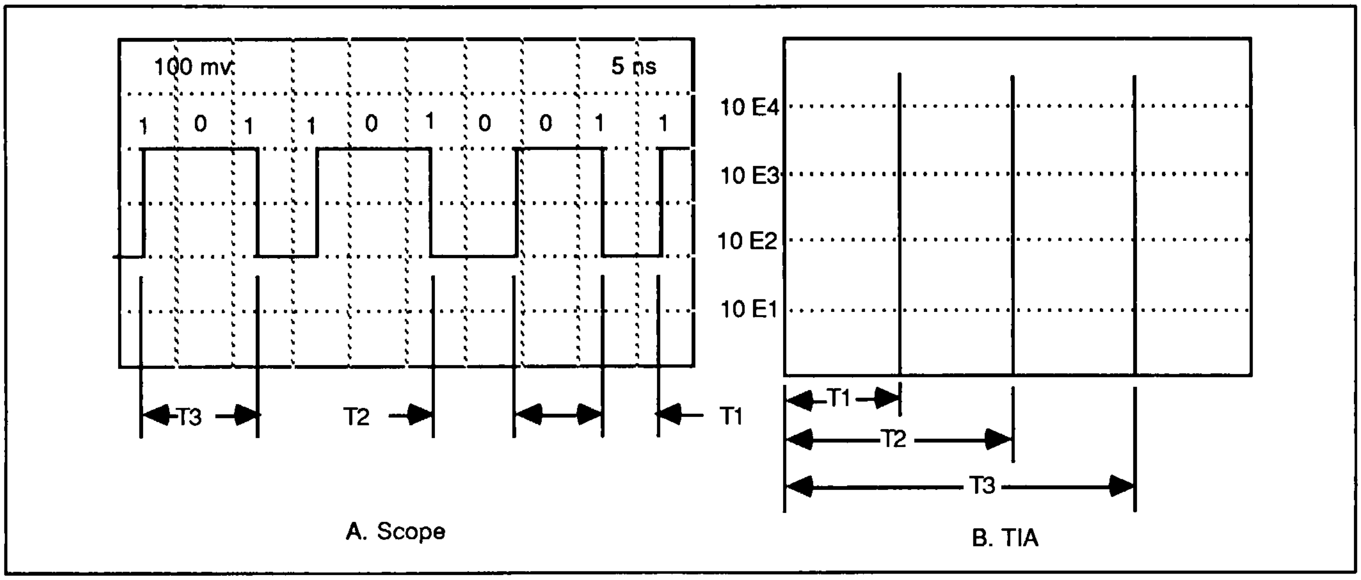
Analysis Requirements

The application of time interval analysis to high density, high data rate recording systems requires consideration in several important areas:

- Convenience of presentation
- Resolution
- Accuracy
- Measurement speed

Convenience of Presentation

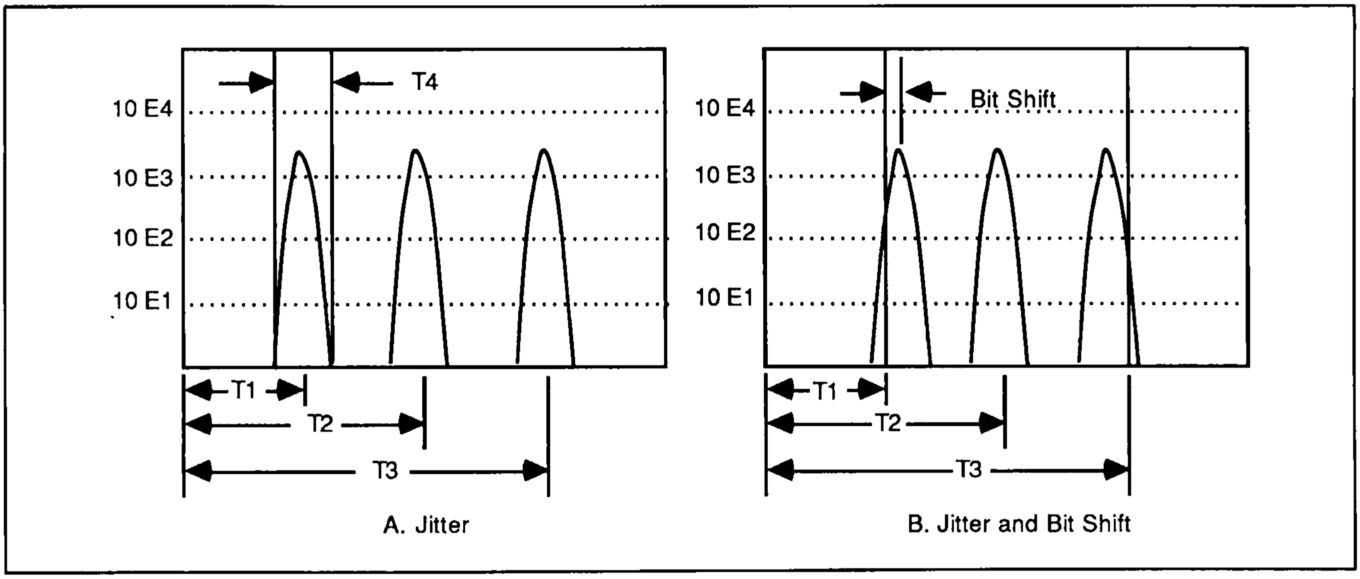
A data base of stored results is key to convenience. Many tests may be applied to the data base, with the re-



A. Scope

B. TIA

Figure 4. An ideal MFM encoded signal: (a) scope; (b) TIA.



A. Jitter

B. Jitter and Bit Shift

Figure 5. Degraded MFM encoded signals: (a) jitter; (b) jitter and bit shift.

sults presented in easy-to-interpret ways. The previous paragraph highlighted some of these, such as histograms, margin windows, and movable cursors. Mathematical analysis over user-defined areas of data, such as statistical mean, standard deviation, and sum would be useful. Standard user interfaces to printers and controllers should be provided. Many other features can be imagined.

Resolution

As data rates climb, time interval measurement resolution requirements get smaller and smaller. For single shot measurements, resolution can be no better than the uncertainty of the quantization process. Other measurement uncertainties could degrade resolution. These uncertainties are discussed under accuracy considerations in Table 1. Counting cycles of a reference time base, between start and stop triggers, yields resolution equal to the period of the time base. A 1-GHz reference would provide 1 nsec of uncertainty. Better resolution is needed, but higher frequency time bases are limited by practical considerations such as expense and bandwidth. Interpolation techniques can be employed to obtain subnanosecond resolution without the need for high-frequency time bases.[8]

Accuracy

Other factors affecting measurement accuracy must be considered. These, as well as quantization errors, are shown in Table 1 and can be classified as systematic or random. Systematic errors have the effect of biasing the results in one direction and may be removed by periodic calibration. Random errors limit the accuracy of a single shot measurement, but their effect can be reduced by averaging multiple measurements. Averaging can improve resolution by a factor of $(n)^{1/2}$, where n is the number of measurements.

Input noise and trigger level errors are both inversely proportional to the slew rate of the input signal. As such, the user has some control over these uncertainties while the others are dependent upon instrument design. Jitter and long-term time base stability are a function of the time base oscillator. Provisions for the use of an external oscillator would give user influence to these factors. Quantization and differential delays are completely design-related and must be minimized by the instrument designers.

Table 1 — Error Sources

Random Errors	Systematic Errors
Input noise	Trigger level
Quantization	Differential circuit path delays
Jitter (short term time base stability)	Long term time base stability

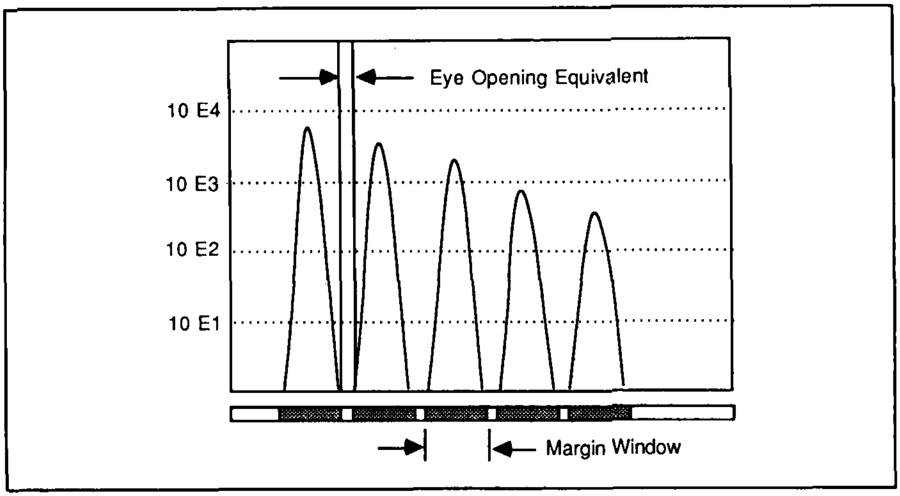


Figure 6. A Miller^2 histogram.

Measurement Speed

Many of the analysis approaches advocated above depend upon fast measurements. Accumulation of a large data base allows statistical analysis, resolution improvement, and the use of histograms, to name a few. To make these techniques practical the data base must be acquired quickly. Sample sizes in the billions are not extraordinary when system error rate must be maintained at 1 in 10^8 or better. Even with the high data rates in emerging DVTRs, and zero measurement processing time, over a minute can be consumed in gathering a billion measurements. Add to this the time to process or simply store a measurement, and the importance of speed becomes clear.

Conclusion

As digital recording gains acceptance in the broadcast industry, suitable techniques for measuring recorder performance become important. The use of powerful error-correction and error-concealment strategies has accompanied the application of digital recording of video signals. These strategies compensate for recorder frailties but at the same time hide the sudden nature of errors. No indicator of impending breakdown of error correction exists. Margin testing should become an adjunct to built-in error detection and correction in DVTRs.

These tests should be quantitative, repeatable, easy to perform, and offer the precision needed to measure signals in the 100 Mbit/sec range. Such tests would provide common assessment techniques between the development lab, quality control, receiving inspection, and end user.

Margin testing as advocated here can be applied to DVTRs now. Test instruments meeting the requirements discussed above are available from multiple sources. One such example is the Model 3100 Time Interval Analyzer from the Kode Div. of Odetics. Test instruments of this type have a history of proven effectiveness in the recording industry.

References

1. *Modern Instrumentation Tape Recording: an Engineering Handbook*, EMI Technology Inc., 1978.
2. J. P. Lerma and C. A. Lindquist, "A Sampling Window Test Method for Evaluation of Phase-encoded Recorded Systems," *Proc. 1976 Intl. Telemetry Conf.*, Los Angeles, Calif., 1976, pp. 541–547.
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6. N. D. Mackintosh, "Evaluation of Disk Drives by Margin Analysis," Century Data Systems, Anaheim, Calif.
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8. Bruce Greenwood, "Fast and Precise Timing Measurements," *Test & Measurement World*, Sept. 1986.

1987 FINANCIAL REPORTS

Statement of Income and Expenses and Changes in Balances of Funds — Year Ended December 31, 1987

	General Fund		Reserve Fund	Building Fund	December 31, 1987 Combined	
INCOME						
Membership dues		$ 534,418				$ 534,418
Test film sales	$ 282,450				$ 282,450	
Less: Direct costs	223,208	59,242			223,208	59,242
Technical conferences						
Income from registrations, exhibits, banquets, etc.	1,776,158				1,776,158	
Less: Direct costs	517,144	1,259,014			517,144	1,259,014
Interest income		65,622	$ 85,533			151,155
Total Income		1,918,296	85,533	—		2,003,829
EXPENSES						
Publications						
Cost of publishing Journal, books, reprints, etc.	781,942				781,942	
Less: Advertising revenue and sales to non-members	442,704	339,238			442,704	339,238
Membership records and promotion		89,649				89,649
Engineering services		223,642				223,642
Office salaries		204,185				204,185
Occupancy (net of rental income — $53,860)		42,871				42,871
Payroll taxes		53,099				53,099
Retirement plan		67,634				67,634
General and administrative		264,104				264,104
Sections and chapters		85,106				85,106
Administrative committees		6,774				6,774
I.S.O. Secretariat		28,714				28,714
Affiliations		16,693				16,693
Other expenses — net		15,637				15,637
Total Operating Expenses		1,437,346	—			1,437,346
EDP equipment and system development		9,324				9,324
Total Expenses		1,446,670	—	—		1,446,670
Excess of Income (Expense) for Year		471,626	85,533	—		557,159
Fund Balances, beginning of year		1,089,356	956,750	$1,792,404		3,838,510
Transfers between funds		(500,000)	500,000			—
Fund Balances, end of year		1,060,982	1,542,283	1,792,404		4,395,669

1987 FINANCIAL REPORTS

Balance Sheet
Society of Motion Picture & Television Engineers, Inc.
December 31, 1987

	General Fund		Reserve Fund		Building Fund	December 31, 1987 Combined	
ASSETS							
Cash							
Checking accounts	$ 173,508					$ 173,508	
Money market and savings	1,133,951		$ 147,739			1,281,690	
Petty cash	400	$1,307,859		$ 147,739		400	$1,455,598
Investments							
Certificates of deposit, due August 1988 through October 1990			1,193,000			1,193,000	
Corporate bonds — at cost (market $69,700)			85,640			85,640	
Government Security Income Fund — at cost (market $101,600)			105,426	1,384,066		105,426	1,384,066
Accounts receivable							
Test film and publications	147,469					147,469	
Accrued interest			10,478			10,478	
Other	1,943	149,412		10,478		1,943	159,890
Inventory of test films — at cost		123,759					123,759
Prepaid expenses							
Employees' retirement plan	70,597					70,597	
Future conferences	58,906					58,906	
Other	9,439	138,942				9,439	138,942
Land and building, White Plains, New York — at cost					$1,792,404		1,792,404
Equipment — Test film, office furniture and computer		3					3
Total Assets		1,719,975		1,542,283	1,792,404		5,054,662
LIABILITIES AND FUND BALANCES							
Accounts payable	$ 232,145					$ 232,145	
Payroll withholding taxes	206					206	
Employees' retirement plan contribution	77,015	$ 309,366				77,015	$ 309,366
Deferred income							
Membership dues paid in advance	300,363					300,363	
Advance payment for test films, etc.	10,497					10,497	
Future conferences	38,767	349,627				38,767	349,627
Fund Balances		1,060,982		$1,542,283	$1,792,404		4,395,669
Total Liabilities and Fund Balances		1,719,975		1,542,283	1,792,404		5,054,662

Accountant's Report

To the Members and Board of Governors of the Society of Motion Picture and Television Engineers, Inc.

I have examined the balance sheet of the SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS, INC. as of December 31, 1987 and the related statement of income and expenses and changes in balances of funds for the year then ended. My examination was made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and other auditing procedures as I considered necessary in the circumstances.

In my opinion, the accompanying balance sheet and statement of income and expenses and changes in balances of funds present fairly the financial position of the Society of Motion Picture and Television Engineers, Inc. at December 31, 1987 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

Owen J. Flanagan, Certified Public Accountant
60 East 42nd Street, New York, N.Y. 10165