A High-Quality Optical Sound Recording System Using a Scanned Laser Beam

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A unique 16mm variable-area sound recording system using a scanned laser beam has been developed by Yokohama Cinema Labs. Inc. under the technical guidance of NHK Technical Research Labs. of the Japan Broadcasting Corporation. This system (U.S. patent approved) has no mechanically moving parts, and the limits of the exposed area depend only on the sound input signal. Its purpose is to extend the frequency bandwidth of the sound record. The frequency bandwidth of the reproduced signal is limited by the characteristics of the film and by the theoretical limits imposed by the reproducing aperture. By virtue of the high intensity of the laser beam, a low-speed photographic film having high resolution can be used as a recording medium. This makes possible the direct recording on color print film, which would be impossible with a conventional recorder. Performance data for Eastman color print film type 7381 processed with normal soundtrack development were as follows: frequency response was − 3 dB at 10 kHz with a reproducer aperture of 12 µm; distortion was 2.2% at 400 Hz, with 80% modulation.

It is generally accepted that magnetic sound recording is superior to optical recording in overall sound quality. Useful features of the optical sound record are its low cost, the greater safety of its permanence, and its greater suitability for the large distribution of commercial films for TV and release prints for theatrical use.

In optical recording, several processing operations are cascaded, and the final performance is determined by the successively applied modulation transfer functions of each piece of equipment and type of material employed. These include the performances of the recorder, negative film, printer, print film, and reproducer. To improve the performance of conventional optical sound recording, it is believed for the most part that what must be improved is the performance of the recorder and of the sound negative film as such.

During our engineering discussions about the feasibility of applying a laser beam to sound recording, a completely new optical sound recording system evolved. It has been developed to the prototype stage (Fig. 1) by Yokohama Cinema Labs. Inc. under the technical guidance of NHK Technical Research Labs., Japan Broadcasting Corporation.

Conventional Optical Soundtrack Parameters Incorporated into the System

Of the two possible types of optical sound records (variable-density and variable-area), only the variable-area track is used at present in almost all applications. Therefore, it was chosen as the basis for the new development, and the bilateral recording pattern, in general use for motion-picture sound records, was postulated for the direct laser beam recording on the film.

The width of the soundtrack is 1.80 mm for 16mm film. An equalizer incorporated in the sound reproducer was adjusted so that the output signal level at each frequency was within 0.5 dB up to 7 kHz when an SMPTE multifrequency test film was reproduced. The frequency response characteristic of the recording equalizer and the aperture effect in the reproducer are shown in Fig. 2 and Fig. 3, respectively.

System Description

The system consists mainly of an air-cooled argon ion laser (λ = 514.5 nm), an acoustooptical light modulator (AOM), an acoustooptical deflector (AOD), and a 100-kHz pulse-width modulation (PWM) circuit, which converts the audio input into PWM signals. The laser beam is made to continuously scan the soundtrack area at right angles to the direction of the film transport. This is achieved by means of the AOD, which in turn is driven by a 100-kHz sawtooth signal. Simultaneously, the laser beam is pulse-width modulated by means of the AOM, which is driven by a 100-kHz PWM signal.

The block diagram of the system (Fig. 4) shows the layout of the basic components of the system. Figure 5 shows how the AOD scanning signal and the AOM pulse-width-modulated signal combine and generate the variable-area soundtrack exposure on the film. The distance between successive scans has been exaggerated for better visualization of the working principle.

The layout and operation of the laser beam are illustrated in Fig. 6. As a first step, the light beam from the argon ion laser is pulse-width modulated in the AOM

Fig. 1. Overall view of a prototype 16mm laser beam sound recorder.

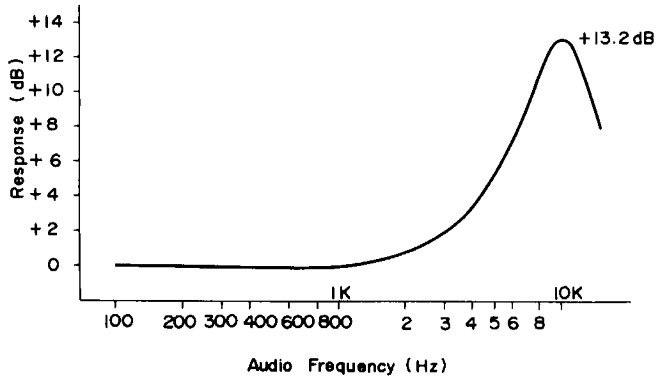

Fig. 2. Frequency response characteristic of a recording equalizer.

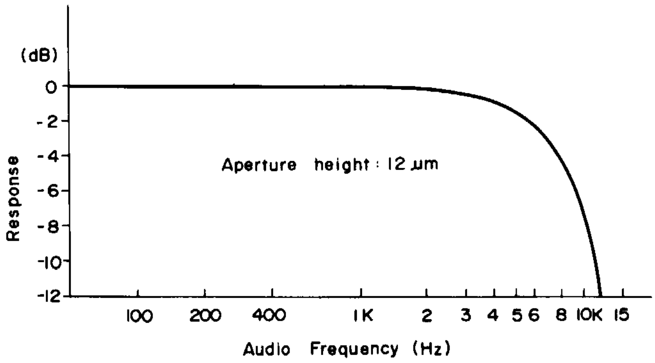

Fig. 3. Calculated aperture effect in a sound reproducer.

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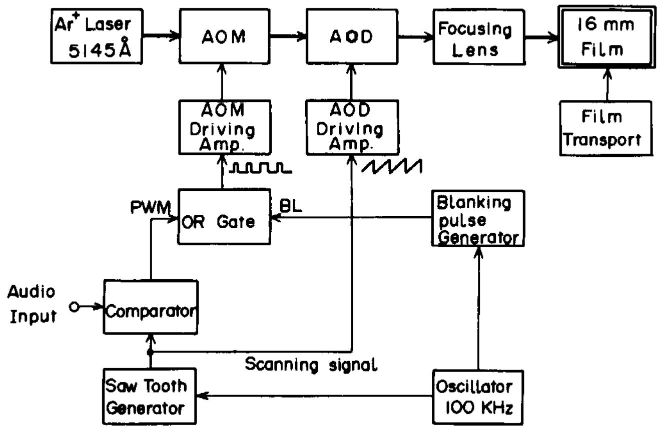

Fig. 4. Block diagram of the laser beam sound recorder.

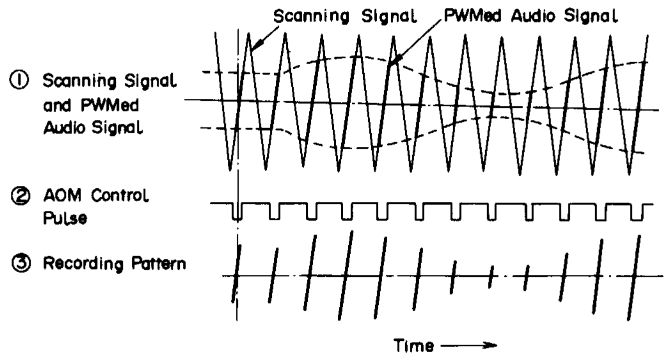

Fig. 5. Schematics of the soundtrack waveform generation.

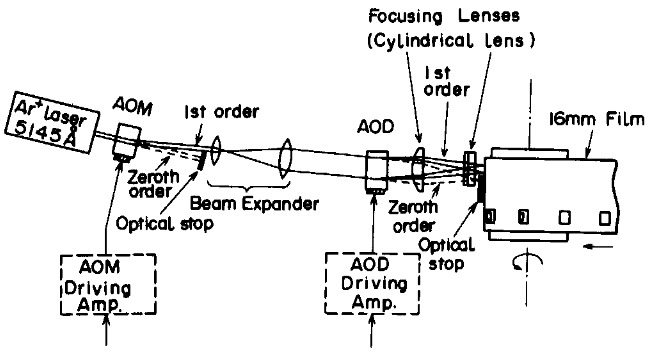

Fig. 6. Basic layout of the main optical components of the laser beam sound recorder.

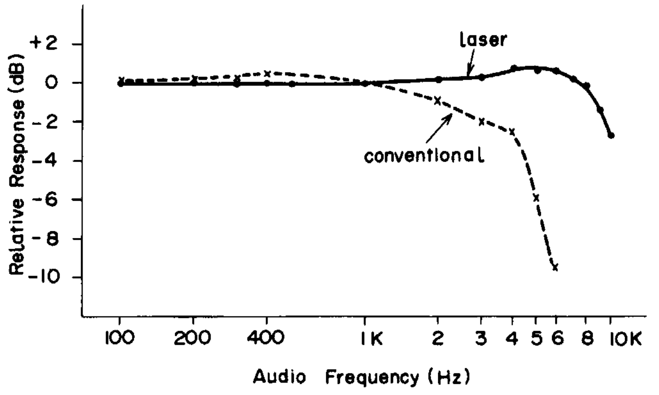

Fig. 8. Overall frequency response for direct print recording with the laser beam sound recorder on Eastman color print film type 7381.

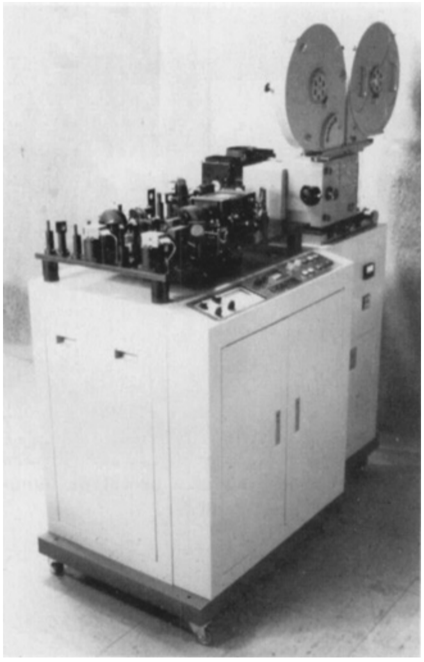

Fig. 7. Optical subassembly of a prototype 16mm laser sound recorder.

at 10-μs intervals in response to the amplitude of the audio signal. As is normal for acoustooptical modulation, the modulated beam is separated into a zero-order and a first-order beam. Only the first-order beam is used in the new recording system, while the zero-order beam is blocked by an optical stop. Next, the diameter of the first-order beam is expanded to the size of the AOD aperture. The beam is then deflected by the AOD and is again separated into a first-order and a zero-order beam. Both beams are now converged to form spot images by means of a pair of cylindrical lenses. The first-order beam is focused onto the 16mm film, while the zero-order beam is blocked by a fixed optical stop in front of the film.

The theoretical diameter of the spot on the film is 40 μm in the direction of deflection and 4.1 μm in the direction of film transport. Some of the main specifications of key components are shown in Table I. Figure 7 shows the optical subassembly after removal of the dust cover.

Inherent Capability of the Laser Beam Sound Recorder

Due to the nature of the recorder itself, a wideband frequency response can be obtained. The theoretical limiting frequency extends up to one half of the carrier frequency, that is, up to 50 kHz for the carrier frequency of 100 kHz designed into the system. By virtue of the high intensity of the laser beam, a low-speed photographic film having high resolution can advantageously be used as a recording medium. Thus, direct recording on color print film can be achieved easily, which is impossible with a conventional recorder.

Performance of the Experimental Prototype

In direct recording on Eastman color print film type 7381, the overall frequency response is within +1 dB to -3 dB up to 10 kHz (Fig. 8), and it can be said that the bandwidth is twice that of the ordinary recorder. Distortion was measured at 2.2% at 400 Hz, with 80% modulation, and it was acceptable for normal listening conditions. The dynamic range, specified by signal-to-noise ratio at 100% modulation, was measured at 48 dB and still requires further improvement (Table II).

There are two causes for the insufficient dynamic range: one is deemed to be due to film noise, as with conventional recorders, and the other is laser noise inherent in the system. The film noise can be overcome through the incorporation of a so-called "noiseless system" having features similar to those in use for many years with conventional recorders. As far as the laser noise is concerned, there is room for improvement through the use of a feedback-type noise-reduction system as already in use in other laser applications. With the future incorporation of these two additional improvements, it can be estimated that the dynamic range of the laser recorder will not be inferior to that of the conventional type of recorder.

In the case of negative-to-positive systems, the laser beam sound recorder also is advantageous for the recording of the

Table I. Basic parameters of the laser beam sound recording system.

Laser	air-cooled Ar$^+$ laser λ = 514.5 nm, 5 mW
AOM (made by Datalight Inc., DLM-1)	rise and fall time — 50 ns
AOD (made by Anderson Labs, BD-100)	resolution — 100 spots access time — 4 μs

Table II. Distortion and dynamic range of the laser beam sound recorder compared with a conventional optical sound recorder.

	Distortion (400 Hz, 80% modulation)	Dynamic Range (SNR at 100% modulation)
Laser beam recorder	2.2%	48 dB
Conventional optical recorder	5.0%	about 52 dB

sound negative because the use of a high-resolution sound negative stock adds to the high performance of the recorder itself. Experiments for obtaining data on the negative-to-positive system are now in progress, and we feel that remarkable improvement will be achieved in comparison with conventional negative-to-positive recording systems.

Conclusion

A unique 16mm variable-area optical sound recording system applying laser technology has been developed. It is intended for enlarging the frequency bandwidth of the recorded audio signal and for recording on a film with very low speed but having high resolution. At present, experiments have shown that good sound quality with a 10-kHz-bandwidth can be obtained using 16mm color film.

This paper only reports on the direct recording system for color print film. For the negative-to-positive system, the laser beam sound recorder is more advantageous than the conventional mechanical recording system. Experiments on negative-to-positive application of the new system were completed in September 1978, and the results obtained were superior to the performance of the direct recording system. The bandwidth was 10 kHz (response down by less than 0.5 dB), cross modulation (8.5 kHz–8.1 kHz) was 1.3%, waveform distortion (400 Hz, 80% modulation) was 1.8%, and dynamic range was 52.5 dB. The negative-to-positive system has been in successful operation since January 1979. The results of further tests will be submitted in more detail at a future date.

Acknowledgments

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Measuring Camera-Tube Resolution with the RCA P200 Test Chart

By R.G. NEUHAUSER

The RCA P200 test chart was developed to eliminate most of the variables involved in the process of measuring the resolution capabilities of a television camera tube. The test pattern produces measurements that are relatively independent of video-amplifier frequency response and eliminates signal variation or test-pattern brightness variations across the tube as a factor in the measurements. The pattern facilitates beam focus to assure minimum astigmatism and analysis of the astigmatism present in the system at the best focus. The use of narrow-band video-amplifier response in conjunction with this pattern greatly reduces noise and increases the accuracy of measurements. The P200 test chart also allows accurate measurement of the resolution of tubes with very high resolution characteristics.

Use of Limiting Resolution vs. Measurement of Resolution Using an Oscilloscope

The use of *limiting resolution* as a measure of a tube's resolution fidelity is usually very subjective and, therefore, given to error. (The limiting resolution of a television display is defined as: the limiting fineness of detail in a spatial pattern reproduced on that television display that can be discriminated by a normal observer at a standard distance from the display equal to a fixed multiple of the display picture height.) An even more compelling reason for abandoning the process of using limiting resolution for the evaluation of a camera tube is the fact that the adjustment of camera beam and lens focus for maximum limiting resolution is different from the point of focus adjustment required for maximum subjective sharpness of the displayed television picture.

A more accurate method of determining resolution involves the measurement, by means of an oscilloscope, of the response of a camera tube to a line pattern whose lines are calibrated in TV lines per picture height (Fig. 1). This measurement must be made with the aid of a test method that is relatively independent of tester judgment and test-equipment variations. A great deal of frustration is encountered when it is attempted to bring measurements, taken with one test set or piece of test equipment, into agreement with measurements made elsewhere on the same tube. Although each tester is sure that his video amplifier is flat up to 8 or 10 MHz within ±0.5 dB, measurements of amplitude response usually differ significantly. The technique of testing a high impedance video preamplifier for flat response is, then, a difficult one and one subject to many pitfalls that produce errors. As a result, differences in measurements by factors of 2 to 1 can be experienced between test equipments in various laboratories.

The result of this frustration was the development of the predecessor to the P200 test pattern. This initial test pattern was first used to evaluate the resolution of some high-resolution camera tubes. The problem at this time was the increased noise in the 20-MHz-bandwidth video-amplifier-system signal needed to handle the signal from a tube capable of some response at 1600 TV lines. Because the noise in a vidicon-tube video amplifier varies as the $^3/_2$ power of the bandwidth, accurate measurements were very difficult to achieve. The method developed to circumvent this problem, a method still used with the current P200 test chart, is as follows.

Use of Rotated Line Patterns

The test pattern is designed with line patterns that are rotated from their usual vertical orientation (Fig. 2) so that the beam traverses them more slowly. In consequence, the signal output from these line

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