Frequency characteristics of optical slits

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MR. LIVADARY in the accompanying article treats of the relative efficiency of different optical slits and their frequency characteristics in connection with sound recording and reproduction. This discussion covers sound recording by means of a glow lamp and sound reproduction of "variable area" and "variable density" sound tracks.

THE art of sound recording deals with the problem of registering sound upon a convenient medium in a manner that will permit distortionless reproduction. The sound engineer is confronted with problems of diversified nature, most of which are intimately related to all branches of modern science.

Ordinarily, sound originates on a stage or out-doors and the proper method of "pick-up" with a microphone involves a study of the acoustics of the surrounding medium; this in turn, yields valuable information as to proper materials to be used in the construction of sets, methods of soundproofing, correct microphone placement and general stage technique. From this point on, the feeble voice energy picked up by the microphone must be sufficiently amplified to make possible its registration upon the recording medium. This requires proper design and reliable operation of practically distortionless amplifiers and associated indicating and monitoring systems.

The recording medium itself may be film, wax, magnetic wire or any other suitable material. The proper method of registration largely determines the quality of the recorded sound. In this article a study will be made of the relative efficiency of various methods used in registering sound on film at the present time, together with a discussion of the frequency characteristic of sound reproduced from film as affected by the optical system of the sound projector.

The material under study is divided in two parts only one of which is covered in this issue. This part deals with sound recording by means of a glow lamp and sound reproduction of variable density and variable area sound tracks.

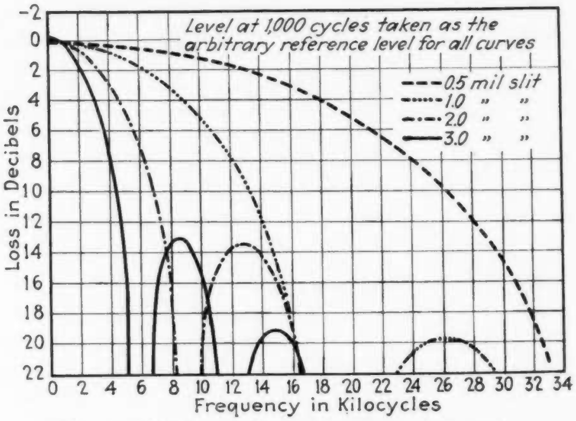

Fig. 1—Fixed optical slit frequency characteristics for variable density and variable area sound track projection and variable density sound recording

From the very inception of the art of recording the speed of the film has been taken as ninety feet per minute; this we will designate by v. We will assume that a glow lamp is used to expose film through an optical slit of fixed dimensions and that the voice currents are superimposed upon the normal excitation of this lamp, causing its instantaneous light intensity to vary in direct proportion to the current through the lamp.

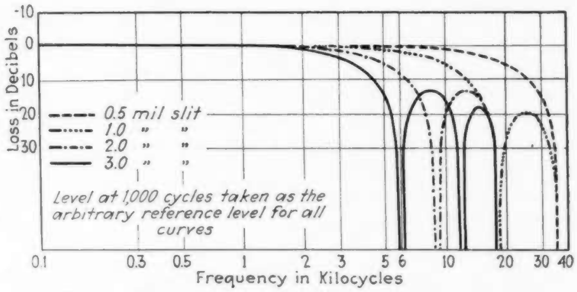

Fig. 2—Frequency characteristics as in Fig. 1 with the frequency axis plotted on log scale to show voice frequency range in detail

The following symbols will be used:

I_0 = unmodulated glow lamp intensity.
$i = I_0 (1 + m \cos \omega t)$ = instantaneous intensity of glow lamp.
m = per cent of modulation of the lamp.
f = frequency to be recorded.
$\omega = 2\pi f$.
t = time.
S_0 = width of optical slit in the direction of motion of the film.

As the film moves with velocity v, any given point of it remains in the field of light of the optical slit for a time $\frac{S_o}{v}$. During this time the exposure varies in proportion to the change in intensity of the glow lamp. If we consider an infinitesimal element as it passes before the slit, we may write its exposure as follows:

$$E = \int_{t_1}^{t_2} I_o\,(1 + m \cos \omega t)\,dt \qquad (1)$$

t_1 = time film element enters light field.

t_2 = time film element leaves light field $= t_1 + \frac{S_o}{v}$

This integral reduces to the following expression:

$$E = \frac{S_o I_o}{v} \left\{ 1 + m \sqrt{\left(\frac{\sin \frac{\omega S_o}{v}}{\frac{\omega S_o}{v}} \right)^2 + \left(\frac{\cos \frac{\omega S_o}{v} - 1}{\frac{\omega S_o}{v}} \right)^2} \cdot \cos\left(\omega t_1 + \frac{\omega S_o}{2v}\right) \right\} \qquad (2)$$

The exposure of the film is shown to be made up of two parts: a fixed exposure $\frac{S_o I_o}{v}$ and a variable exposure

$$m \cdot \frac{S_o I_o}{v} \sqrt{\left(\frac{\sin \frac{\omega S_o}{v}}{\frac{\omega S_o}{v}} \right)^2 + \left(\frac{\cos \frac{\omega S_o}{v} - 1}{\frac{\omega S_o}{v}} \right)^2} \cdot \cos\left(\omega t_1 + \frac{\omega S_o}{2v}\right) \qquad (3)$$

This variable part has a coefficient which varies with frequency and a phase shift which is linear with respect to frequency.

A study of this expression leads to the conclusion that film exposed by this method registers the original sound with increasing attenuation to higher frequencies and without phase distortion, as shown by the linearity of the phase displacement coefficient.

The frequency characteristic obtained depends upon the frequency, the velocity of the film and the width of the slit. The last quantity is the only factor that we may reasonably control, since it is undesirable to discriminate in the range of frequencies to be recorded or to change the velocity of the film.

The accompanying table shows the attenuation loss in decibels for frequencies from 35 to 33,000 cycles, computed for optical slits from half a mil to three mils in width. It also shows the phase shift for the same frequency range.

Figures 1 and 2 show the results of the table in graphical form. The graphs on figure 2 are plotted on log paper in order to spread out the voice frequency range. Fig. 3 shows the phase shift.

It is evident from these curves that with very narrow slits high quality recording is possible, without need for equalization on account of the drooping characteristics at the high frequency end.

It may be of interest to note that there is always a definite frequency whose wave length on the film equals the width of the recording slit. As this frequency is approached the attenuation of the film sound record rises rapidly, becoming infinite when the wave length on the film is equal to the slit width. On account of this phenomenon we have the peculiar result that a 2 mil slit, for example, which has a better overall frequency characteristic than a 3 mil slit, cannot possibly record, or reproduce, as we will show later, 9,000 cycles per second, whereas the 3 mil slit is capable of doing it with an attenuation of only 13.5 decibels.

It so happens that in the analysis of sound reproduction from film the mathematical expressions for the value of the photoelectric currents in the cell of the sound projector are of the same form as (1). In the case of the variable density sound track the photoelectric current is given by the integral

$$kT_o \int_{S_1}^{S_2} \left(1 + m \cos \frac{\omega s}{v}\right) ds \qquad (4)$$

while for the case of the variable area track the cell current is given by

$$\frac{kb}{2} \int_{S_1}^{S_2} \left(1 + m \cos \frac{\omega s}{v}\right) ds \qquad (5)$$

where

k = photoelectric constant,
T_o = unmodulated transmission of sound track,
S_1 = point of the sound track entering field of optical slit,
S_2 = point of sound track leaving field of optical slit,
b = width of the variable area sound track.

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Attenuation losses for different optical slits

Frequency Cycles per Sec.	Slit Width-0.5 mil Loss-DB	Slit Width-0.5 mil Phase Shift Degrees	Slit Width-1.0 mil Loss-DB	Slit Width-1.0 mil Phase Shift Degrees	Slit Width-2.0 mils Loss-DB	Slit Width-2.0 mils Phase Shift Degrees	Slit Width-3.0 mils Loss-DB	Slit Width-3.0 mils Phase Shift Degrees
35	0.00	— 4.82	— 0.04	— 9.65	— 0.17	—19.3	— 0.38	—28.95
60	0.00	— 4.7	— 0.04	— 9.4	— 0.17	—18.8	— 0.38	—28.2
100	0.00	— 4.5	— 0.04	— 9.0	— 0.17	—18.0	— 0.38	—27.0
200	0.00	— 4.0	— 0.04	— 8.0	— 0.17	—16.0	— 0.38	—24.0
500	0.00	— 2.5	— 0.04	— 5.0	— 0.17	—10.0	— 0.26	—15.0
1000	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0
2000	0.05	5.0	0.16	10.0	0.54	20.0	1.30	30.0
3000	0.12	10.0	0.40	20.0	1.50	40.0	3.74	60.0
4000	0.17	15.0	0.73	30.0	2.88	60.0	7.32	90.0
5000	0.26	20.0	1.06	40.0	4.76	80.0	14.0	120.0
6000	0.36	25.0	1.60	50.0	7.50	100.0	∝	—30.0
7000	0.58	30.0	2.24	60.0	11.46	120.0	16.9	0.0
8000	0.71	35.0	2.98	70.0	18.10	140.0	13.3	30.0
9000	0.92	40.0	3.88	80.0	∝	—20.0	13.1	60.0
10000	1.12	45.0	4.92	90.0	20.0	0.0	15.3	90.0
11000	.....	.....	.....	.....	.....	.....	21.20	120.0
12000	.....	.....	7.64	110.0	13.70	40.0	.....	.....
13000	.....	.....	.....	.....	.....	.....	22.72	0.0
13500	.....	.....	.....	.....	13.50	70.0	.....	.....
14000	.....	.....	11.60	130.0	.....	.....	18.56	30.0
15000	2.64	70.0	.....	.....	15.70	100.0	.....	.....
16000	.....	.....	18.24	150.0	.....	.....	19.74	90.0
17000	.....	.....	24.64	160.0	24.90	140.0	.....	.....
20000	5.00	95.0	.....	.....	.....	.....	.....	.....
25000	8.52	120.0	.....	.....	.....	.....	.....	.....
30000	14.38	145.0	.....	.....	.....	.....	.....	.....
33000	21.0	160.0	.....	.....	.....	.....	.....	.....

Reference Frequency—1000 cycles per second.
This table gives tabulated data for figures 1, 2 and 3.

Frequency characteristics of optical slits

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The similarity of the integrals (4) and (5) with that of (1) is due to the fact that in reproducing sound a constant intensity light is used which is focused upon an optical slit. This slit is, in turn, focused upon the sound track which is moving at a velocity v. As the light passes through the film it becomes modulated by the variable density or area track and then proceeds to excite the photocell which is located on the other side of the film. It is evident that the solutions of (4) and (5) must be of the same form as (2).

Naturally, perfect film development is assumed and the dimensions of the slit upon the moving sound track are used rather than the dimensions of the slit itself, in figuring the frequency characteristic of the reproduction.

Therefore, curves 1, 2 and 3 illustrate also the frequency characteristic of the sound projector.

It is important to note that a very strong tendency exists among sound recording studios to release entirely with re-recorded sound. Re-recording is the process of reproducing sound through a special sound projector and recording it as though it had originated on a sound stage. This is often necessary because it renders easier and more economical the addition of effects and music to the original sound, it simplifies operation in the film laboratory and further lends itself to better sound perspective and reality.

The importance of a very sharp focus in the optical system of the re-recording apparatus is very evident. One mil is the standard focus used at present. Two years ago, when talking pictures were in their infancy, 3 mil focus in the sound projectors was a very common occurrence. This coupled with a similar condition in the optical system of the film recording machines and lack of adequate knowledge of proper film development, account sufficiently for the poor quality of the early talkies and the natural tendency of certain producers to release on discs instead of film. In studios which release on both discs and film, disc releases have dropped from a commanding position to about 30 per cent and the tendency is that they will eventually disappear.

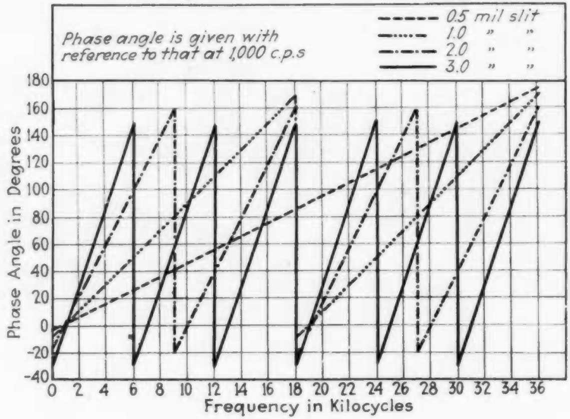

Fig. 3—Phase shift curves for fixed optical slits used in sound recording and projection

The frequency characteristics of variable area sound recording through a fixed dimension slit and variable density recording through a slit of *variable* dimensions will be discussed in a subsequent issue of *Electronics*.