Optimum High-Frequency Bias in Magnetic Recording*

By G. L. DIMMICK and S. W. JOHNSON

RCA Manufacturing Company, Camden, New Jersey

Summary—An experimental study was made of magnetic tapes and films produced by several manufacturers. The effects of bias current upon the frequency characteristic, the reproducing level, and the harmonic distortion are shown. Conclusions are drawn as to the best method of testing a given tape for the optimum value of high-frequency bias.

A high-frequency bias for magnetic recording was first used by W. L. Carlson and G. W. Carpenter in 1921. Since that time there have been differences of opinion regarding the exact cause of the improved linearity and lower distortion produced by this type of bias. Many people subscribe to the theory that the action of the high-frequency magnetic field is to keep the molecules in a constant state of agitation and thus make them more responsive to the lower frequencies required for the recording of speech and music. Others believe that the improved results can be accounted for by the action of the combined high- and low-frequency magnetic fields upon the normal magnetic characteristics of the material in question. Toomin and Wildfeuer[1] attempted to explain the action of a high-frequency bias upon a sound-recording system using a recording medium having permanent-magnet characteristics. Later, Holmes and Clark[2] gave a different explanation of the same phenomena and showed how a magnetic-recording system is analogous in some respects to a push-pull amplifier. The writers of the present paper are of the opinion that the theory advanced by Holmes and Clark adequately explains the observed performance of a magnetic-recording system when various amounts of high-frequency bias are used. The purpose of this paper is to review briefly the above-mentioned theory and to show the effects of high-frequency bias upon the total harmonic distortion, the frequency response, and the output level for four coated magnetic tapes.

Fig. 1 is a simplified diagram showing how the high-frequency bias acts to reduce distortion and noise reproduced from a

* Presented May 18, 1948, at the SMPE Convention in Santa Monica.

permanent-magnet recording medium. The dotted line K shows one half of one of the major hysteresis loops for the magnetic material. The complete loop is symmetrical about the point O. The solid lines OF and OG represent the virgin characteristics of the material plotted in both the positive and negative directions from the magnetically neutral point O. The curves F and G are the ones with which we are most concerned, since the material does not pass through a major loop during the recording process. A high-frequency sine wave L of amplitude S has superimposed upon it lower-frequency waves E and D which are identical and which represent the speech or music being recorded. It is assumed that the magnetic material on which a record is to be made is in a magnetically neutral state before it comes under the influence of the recording head. As a particular point on the magnetic tape approaches the recording air gap, it is magnetized along a series of minor loops which occur at the frequency of the bias. These loops start at point O and progress up curve F. The amplitude of the minor loops increases until the point on the tape reaches the entering edge of the recording gap. The minor loops remain constant in amplitude during the passage across the recording air gap, but they may vary in position if the amplitude of the low-frequency recorded signal varies appreciably during the time the point on the tape is passing across the gap. When the point leaves the gap, the amplitide of the minor loops starts decreasing and finally reaches zero. If the amplitude of the recorded signal was of such value as to cause the ends of the minor loops to reach position a (Fig. 1) when the point on the tape reached the exit edge of the gap, the loops would then decrease in amplitude and recede down curve a-b until point b is reached. This is the residual induction left in the tape at the particular point in question after it has passed over the recording head.

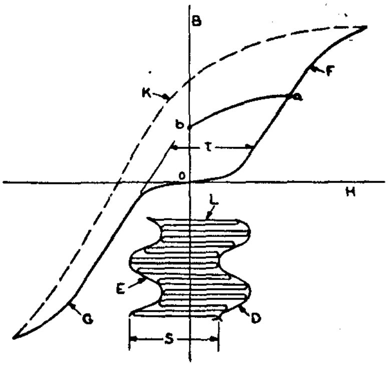

Fig. 1—Diagram showing how virgin-tape characteristic is modulated.

From Fig. 1 it can be seen that one of the functions of the high-frequency bias is to eliminate the effect of the "kink" in the normal characteristics of a permanent-magnet material. This can be done if

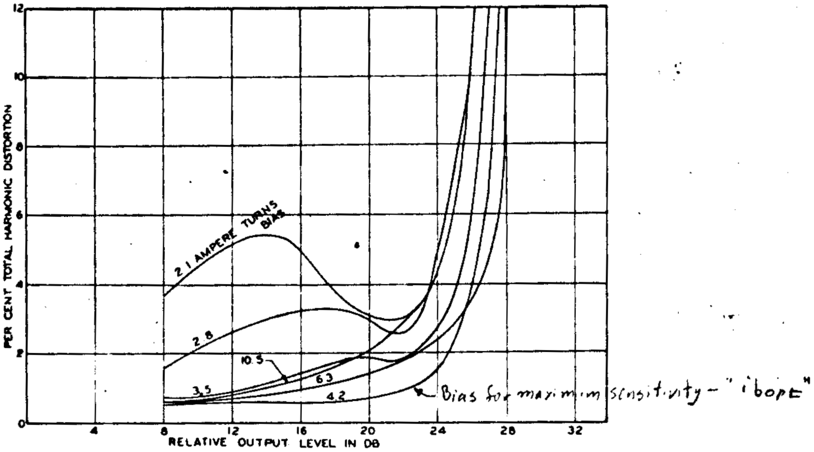

Fig. 2—Distortion-versus-reproducing-level, German Type C tape.

the amplitude S of the high-frequency bias is about equal to the distance t between the straight portions of the curves F and G. Another very important function of the high-frequency bias is to reduce noise from the reproduced signal. It is well known that the amount of noise reproduced from a magnetic-recording medium increases with the residual induction left on the medium after recording. This

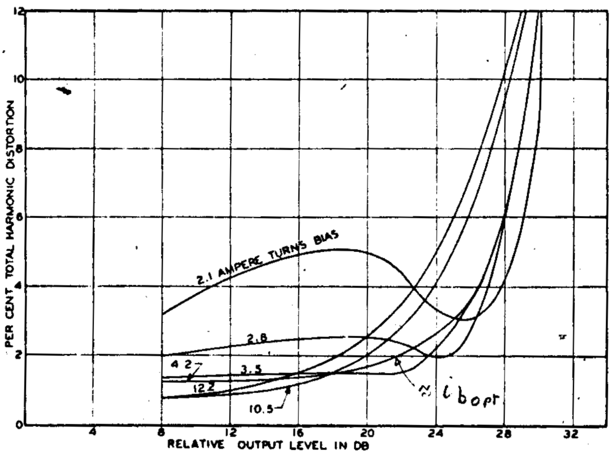

Fig. 3—Distortion-versus-reproducing-level, duPont SW4 tape.

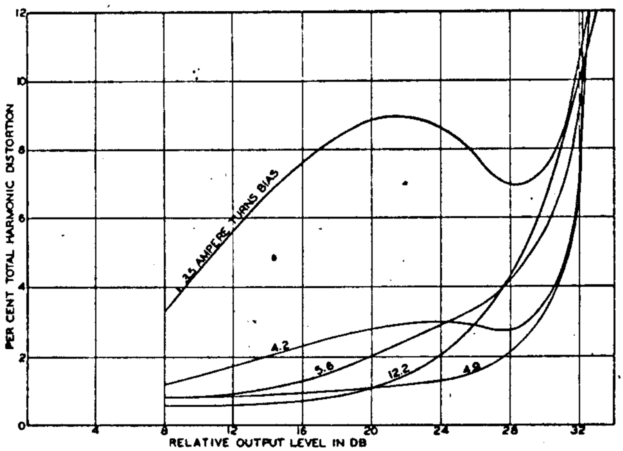

Fig. 4—Distortion-versus-reproducing-level, Minnesota Mining black-oxide plastic tape.

noise is of a random nature and sounds to the ear very much like thermal noise from a resistor, or like "shot effect" from an amplifier tube or phototube. The ear is very sensitive to this type of noise when there are no other reproduced signals to mask it. The high-frequency bias, therefore, serves the important purpose of keeping the recording medium in a magnetically neutral state when no signal is recorded.

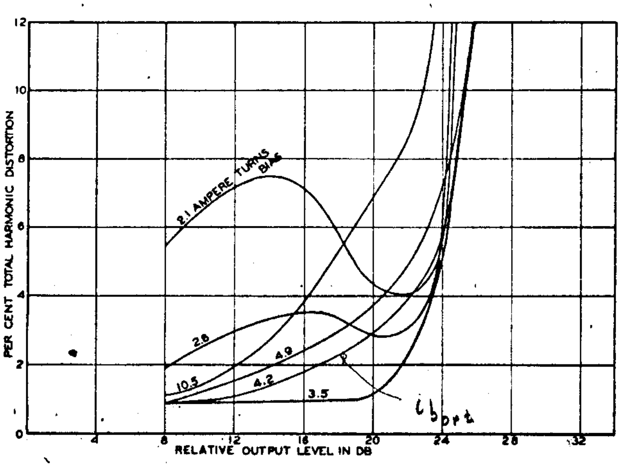

Fig. 5—Distortion-versus-reproducing-level, Minnesota Mining Type RR tape.

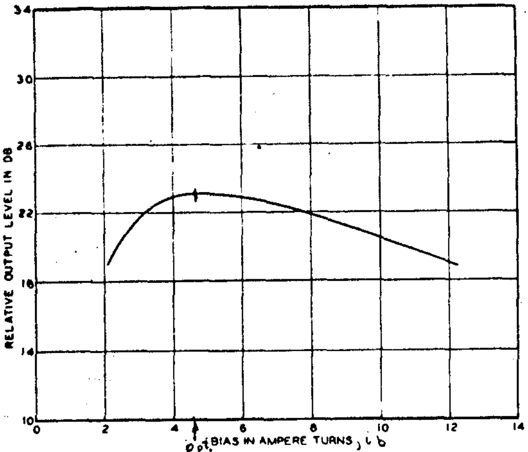

Fig. 6—Output-level-versus-bias, German Type C tape.

In order to determine experimentally the effect of high-frequency bias upon distortion and output level, a $^1/_4$-inch tape recorder and reproducer was so arranged that many of its characteristics could be held constant throughout the tests. The tape speed was set at 15 inches per second, and the over-all frequency characteristic was adjusted to be flat within 1 decibel from 50 cycles per second to 10,000 cycles per second when using German Type C tape with the bias set

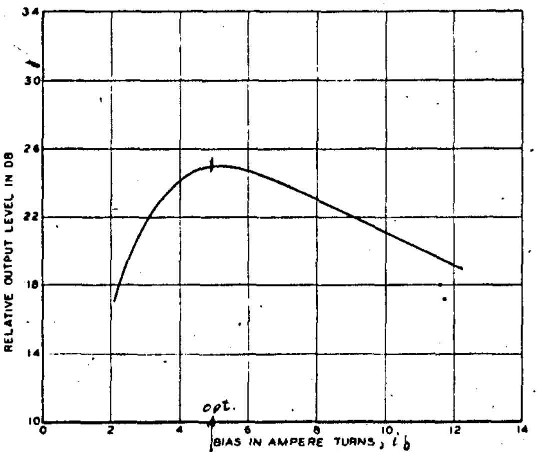

Fig. 7—Output-level-versus-bias, duPont SW4 tape.

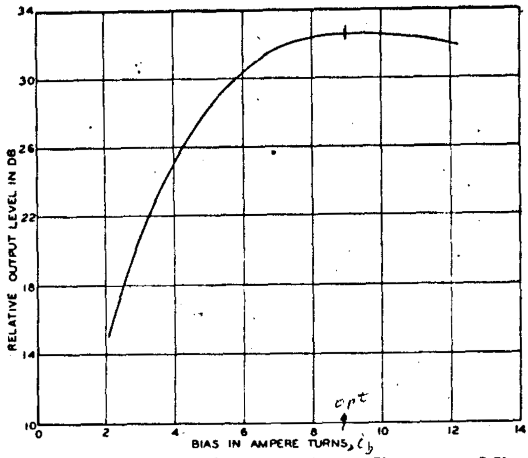

Fig. 8—Output-level-versus-bias, Minnesota Mining black-oxide plastic tape.

at its optimum value. The frequency of the bias was 100 kilocycles. The recording characteristic was flat from 50 to 3000 cycles per second and rose 10 decibels between 3000 and 10,000 cycles per second. Three-foot loops of each of the tapes were used for the tests, and the recorded material was continuously erased before new material was recorded. The erasing frequency was also 100 kilocycles. Ring-type heads of RCA design were used for recording, reproducing, and erasing. The recording gap was 0.001 inch while the reproducing gap was

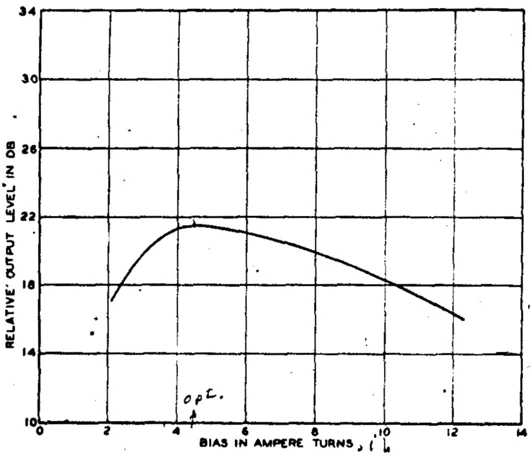

Fig. 9—Output-level-versus-bias, Minnesota Mining Type RR tape.

0.0005 inch. The total distortion introduced by the recording and reproducing amplifiers was about 0.25 per cent. A General Radio Type 732-A total-harmonic-distortion meter was used, and the distortion and output-level measurements were made at a frequency of 400 cycles per second. The gain of the reproducing amplifiers was held constant throughout the tests, in order to have a direct comparison between the output levels for the four tapes tested. These were German Type C, duPont Type SW4, Minnesota Mining black plastic tape, and Minnesota Mining Type RR tape.

Fig. 2 shows a family of curves in which the total harmonic distortion in per cent is plotted against output level in decibels for various

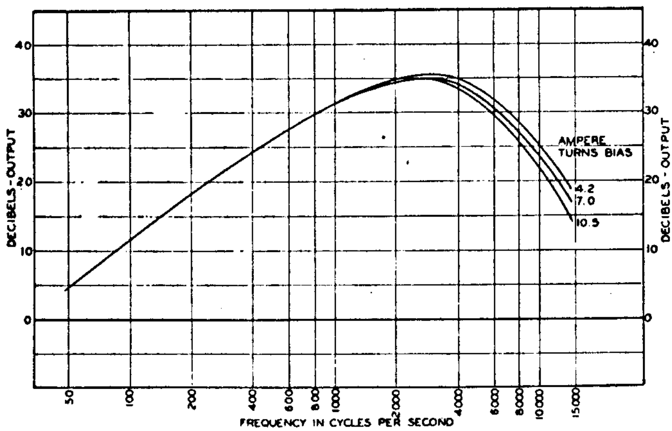

Fig. 10—Frequency response, German Type C tape.

values of high-frequency bias. This family of curves was made with German Type C tape under the test conditions described above. A range of bias values extending above and below the optimum value was chosen. It is quite apparent that the curve made with a bias of 4.2-ampere turns will result in the greatest output with the least distortion. The distortion is less than 1 per cent for output levels below 22.5 decibels, after which the curve breaks sharply. For higher or ~~lower bias values~~, the distortion is greater for a given output level.

In view of the explanation of the recording process based upon Fig. 1, it seems reasonable to expect the distortion curves to be as they are shown in Fig. 2. For low values of bias we should expect the distortion to be relatively low for small recorded-signal amplitudes. This is because the curve *GOF* (Fig. 1) is relatively straight where it passes through the point O. When the signal is increased until the peaks extend beyond the toe portions of curves G and F, the distortion will reach a maximum value. For still greater values of recorded signal the distortion will decrease because the distortion effect of the "kink" in the curve GOF will become a smaller percentage of the total signal. For even greater values of recorded signal, the distortion will rise again because the peaks of the waves will begin to occupy the "knee" portions of curves G and F.

It is assumed that the best value of bias is the one which just eliminates the "kink" in the over-all characteristic and results in a constant slope through the origin O. Any further increase in bias re-

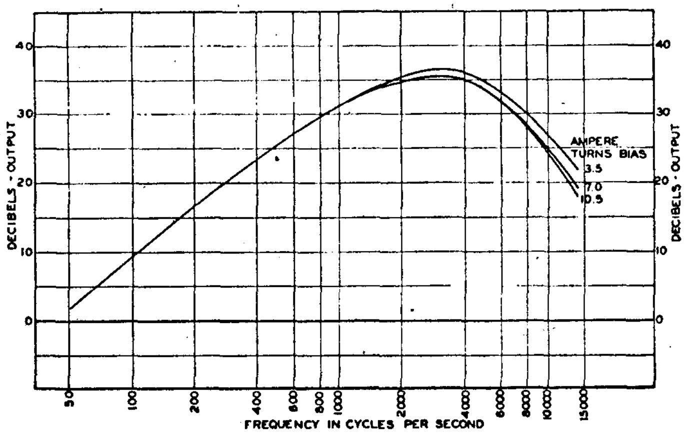

Fig. 11—Frequency response, duPont SW4 tape.

sults in the slope being greater near the origin, and it also results in a reduction in the total effective length of the characteristic curve, due to partial erasing. These two effects account for the fact that for high values of bias the distortion is increased and the overload level is decreased.

It should be pointed out here that the absolute values of the output levels and bias values shown in Figs. 2 to 9 have no significance. A bias of 1.0-ampere turn used with a recording head of one design would not necessarily produce the same effect as the same bias value used with a recording head of another design. Since in this case the same recording head was used throughout the tests, the numerical values of bias are necessary in order to compare one tape with another. The gain of the reproducing amplifiers was held constant throughout the tests in order to make it possible to compare output levels for different tapes.

Fig. 3 shows a family of output-versus-distortion curves for duPont SW4 tape. It may be seen that the best bias value is 3.5-ampere turns. Comparing Fig. 3 with Fig. 2, it will be observed that the overload levels (for optimum bias) are about the same for German Type C and duPont SW4 tape. The distortion values below overload are, however, appreciably higher for the duPont tape.

Fig. 4 shows a family of output-versus-distortion curves for Minnesota Mining black plastic-base tape. It will be observed that the

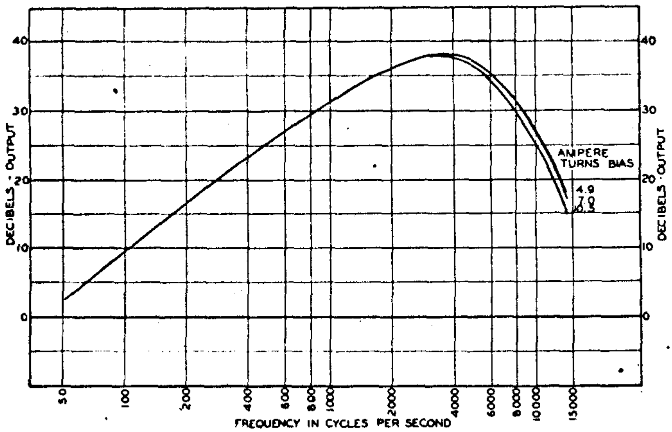

Fig. 12—Frequency response, Minnesota Mining black-oxide plastic tape.

best bias value is 4.9-ampere turns, which is somewhat higher than for the other two tapes. If we arbitrarily assume the overload point to occur at 3 per cent distortion, the overload level (for optimum bias) of Minnesota Mining black tape is 4 decibels higher than for German Type C tape. It will be noticed that the curve for 5.6-ampere turns is much poorer than for 4.9-ampere turns. At 12.2-ampere turns, the curve gets better again but not so good as for the optimum bias. The overload point drops $3^1/_2$ decibels when the higher bias value is used, but this level is still higher than for the German tape.

Fig. 5 shows a family of output-versus-distortion curves for Minnesota Mining Type RR tape. The best bias value occurs at 3.5-ampere turns, which is the same as for duPont SW4 tape. The overload level (for 3 per cent distortion) is 3 decibels lower than for

German Type C tape and 7 decibels lower than for the Minnesota Mining black plastic-base tape. The Type RR tape has compensating advantages over the black type in that it is much easier to erase, requires a lower bias value, and has a lower noise level.

The effect of bias current upon output level for four different tapes is shown in Figs. 6 to 9, inclusive. These curves were made with a constant recording level, and the output level is plotted as a function of bias in ampere turns. The recording level was set to give an output level of 23 decibels for German Type C tape, 23 decibels for duPont SW4, 28 decibels for Minnesota Mining black tape, and 21

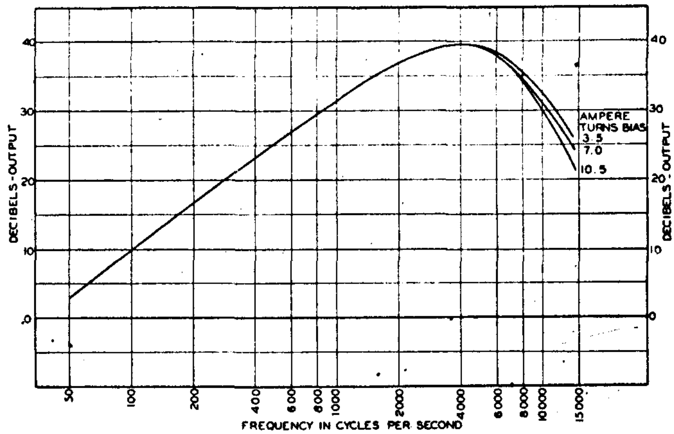

Fig. 13—Frequency response, Minnesota Mining Type RR tape.

decibels for Minnesota Mining Type RR tape. By comparing values on Figs. 2 and 6, it can be seen that for German Type C tape the bias value required for lowest distortion is the same value required for maximum output level. This is a very desirable condition because it means that slight variations in bias about its optimum value will not cause corresponding variations in the output level. For duPont SW4 and Minnesota Mining Type RR tapes (Figs. 7 and 9) the bias required for least distortion occurs slightly below the point of maximum output level. For Minnesota Mining black plastic-base tape, the bias which gives the maximum output is nearly twice the value which is optimum from the standpoint of distortion.

The effect of bias upon frequency characteristic for four tapes is shown in Figs. 10 to 13, inclusive. The purpose of these curves is to show that the bias current produces some erasing of the signal and his effect is greatest at the highest signal frequencies. It will be observed that Minnesota Mining black tape is less affected by bias than the other red-oxide tapes. This is probably because the coercive force for this tape is higher and the effect of demagnetization at high frequencies is less. All three of the American-made tapes have better high-frequency response than the German Type C tape. The curves shown in Figs. 10 to 13 were made without compensation and represent the variation in output voltage of the reproducing head with recorded frequency. The current in the recording head was held constant at all frequencies.

REFERENCES

(1) Hershel Toomin and David Wildfeuer, "The mechanism of supersonic frequencies as applied to magnetic recording," *Proc. I.R.E.*, vol. 32, pp. 664–668; November, 1944.

(2) Lynn C. Holmes and Donald L. Clark, *Electronics*, July, 1945.

DISCUSSION

CHAIRMAN JOHN G. FRAYNE: Mr. Pettus, is the performance of the film drive from the standpoint of velocity or speed variation as good for the position occupied by the magnetic-recording head which is not on the recording drum as compared to the speed variation or flutter which exists in optical recording in which the point of translation is on the drum?

MR. J. L. PETTUS: Are you referring to the recorded reproduction?

CHAIRMAN FRAYNE: I am referring to the position of the record head. How does the speed-recording variation compare to the speed for normal optical film?

MR. PETTUS: Tests of flutter made by optical recording have indicated this 'rive to be considerably improved over the former machines. With the recording .eproducing head in place, which would be adding to the film, our measurements show no serious difficulty in that respect. In brief, we believe that the drag of the recording reproduction head offers nothing objectionable.

CHAIRMAN FRAYNE: Do you have any factual data?

MR. PETTUS: Not at this time.

MR. CRONIN: Mr. Dimmick, in connection with the curves in which you described the percentage of distortion of total distortion versus ampere turns—is it not a problem to know the volume of material that is being magnetized; for example, was there any difference in the thickness of the magnetic film or the pigment? I presume the width of the regions of influence were the same. Could not that be normalized to some quantity stated to unit volume, for example?

MR. G. L. DIMMICK: We have no data on the exact thickness of the four films presented. I believe that the German film is thicker than the films used in the American-manufactured films, but I am not certain. To get that data, we should have to go to the manufacturers of the film itself.

MR. C. R. KEITH: Do you have any particular reason for choosing the position of the sound track that was mentioned in the paper? It appeared that the sound track is placed in exactly the same position as the 200-mil photographic sound track. That is quite possible, but it seemed to me there would be some advantage in having the magnetic track farther away from the sprocket holes.

MR. DIMMICK: That is a very good question, and one for which we probably do not have a complete answer, but one on which the various committees are working. All other things being equal, it would seem best to have the track location in the same place as formerly used for wide-track photographic recording. One might think that it would be best to put the track down the center. I think there is no doubt that you would be freer from the effect of the sprocket holes if you did this; however, you do sacrifice the ability to turn the film around and put two tracks on. I think that there will have to be much work done on this before the final standardization is given for the location of magnetic track.

CHAIRMAN FRAYNE: Have you done any work on $17^1/_2$-mm film?

MR. DIMMICK: No.

MR. L. D. GRIGNON: Do you have any information comparing the impregnated tapes versus the coated tapes that you have shown here today?

MR. DIMMICK: Are you thinking of tape like the German tape? No, we have not, and I think the reason for that is that the Germans themselves became discouraged by the results they obtained from the Type L. The reason for that was that the print-through was too great. You would have one layer against the other, and you get printing too high to tolerate.

MR. GEORGE LEWIN: Is there any optimum value for the width of the track? It would seem to me the wider you make it, the better the signal-to-noise ratio.

MR. DIMMICK: Yes, the same consideration holds for magnetic recording and variable-density recording.

MR. LEWIN: Why did you use only 180 or so? Why not the full width?

MR. DIMMICK: Once again, we did take exactly the same dimensions as had previously been standardized for photographic recording. There is a recording head over the same area formerly covered by the recording light beam, and the reproducing head is the same width as the reproducing light beam.

QUESTION: Do you feel then that if you went to full width that the amount of gain is not sufficient to justify it?

MR. DIMMICK: There are two factors. We believe that the signal-to-noise ratio obtainable from the present width of track is so much greater than formerly available in photographic recording that it is not necessary to go to wider tracks, and tolerance on angle of both recording and reproducing heads gets much worse as the width of the track goes up in width.

MR. LAW: Will the bonding agent in the tape, when used, say in 16-mm work, stand developing without any signal loss?

MR. DIMMICK: I cannot answer that specifically, but I am of the opinion that developing will not harm the tapes. I believe there are in the audience representatives from the tape manufacturers. Possibly they could answer that better.

MR. R. R. HERR: I cannot speak from experience, but certainly nothing that I know of has much effect. There is a plastic oxide binder in which the magnetic oxide is placed, and I am quite sure it will have no effect on the oxide itself which is impregnated in that binder.