BASF

FOR THE BEST RECORDINGS YOU'LL EVER MAKE

The Inventor's Notebook

TECHNICAL BULLETIN #4

EQ

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During a lecture in 1819, Hans Christian Oersted discovered to his surprise that electrical current running through a wire made the wire act like a magnet. In October, 1831, Michael Faraday discovered the reverse effect: that moving a magnet in and out of a coil of wire produced electric current in the coil; and the faster the magnet moved, the more current was produced. These two discoveries led to the development of electricity as a medium of energy. Today we generate electricity by using water or steam pressure to turn shafts with huge magnets attached to them. The shafts and magnets are surrounded by coils of wire so that, as the shaft turns, the moving magnets produce electric current in the coils. If an electric motor is plugged into the current, the electricity flows into the motor's coils and turns the magnets on the motor's shaft: the drill drills, the turntable turns.

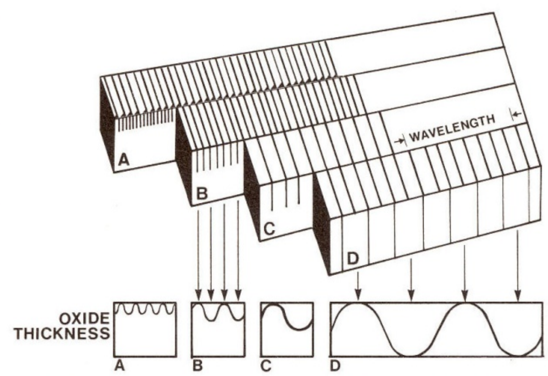
Faraday's discovery also applies to tape recording and playback. A tape head is actually an electromagnet with coils of wire inside. When music is translated into electrical current, the current is sent to the head to act as a magnet putting magnetic print patterns on the tape.

When recorded tape runs past the playback head, the magnetic prints on the tape create a current in the head that is amplified in the chain of audio components and is finally fed to the speakers. The current induced in the head (its output), however, does not depend directly on the magnetic signal on the tape; the current depends on the rate of change in the flux level, or, in other words, on how fast the magnetic prints move past the head, just as in Faraday's coil. Recorded tape not moving past the head generates no signal in the head at all. Since high frequencies have more prints than low frequencies (cf. FIG. 3, "Inventor's Notebook" #3), they have a greater rate of change (they seem to be "moving faster") and, consequently, they have more output. In terms of voltage, the output increases at a rate of 6dB per octave—twice as much output every time the frequency is doubled. To compensate for this increasing output (FIG. 1A), the playback section of a tape recorder has a decreasing slope built into its circuitry (FIG. 1B) so that the increase plus the decrease is "equalized" for a flat response (FIG. 1C). Equalization makes up for the differences in output by making them equal. However, as frequencies increase and the distances between prints (wavelengths) grow shorter, high frequency losses due to such factors as spacing losses in addition to slow tape speed, wide playback gaps, and limitations in the tape cause the 6dB/octave output increase to level off and begin to drop. To solve this problem, the effect of the decreasing slope (B) is removed at a particular frequency point so that the natural high frequency output increase makes up for the treble losses.

FIG 3 from *Inventor's Notebook #3*, "Bias"

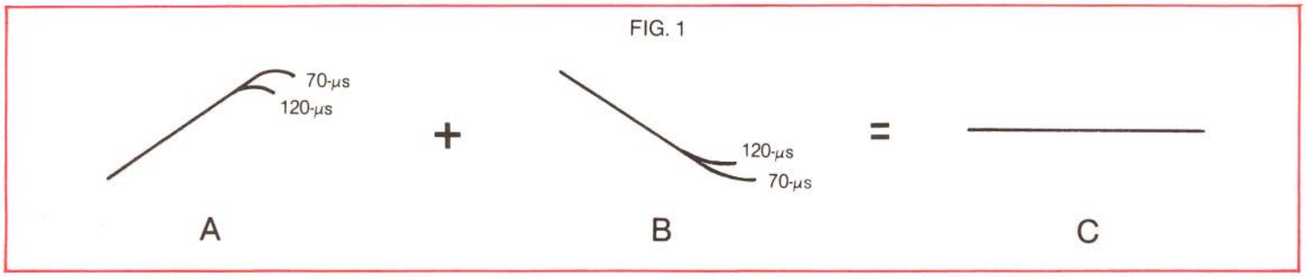
FIG. 3

WAVELENGTH ON OXIDE COATING

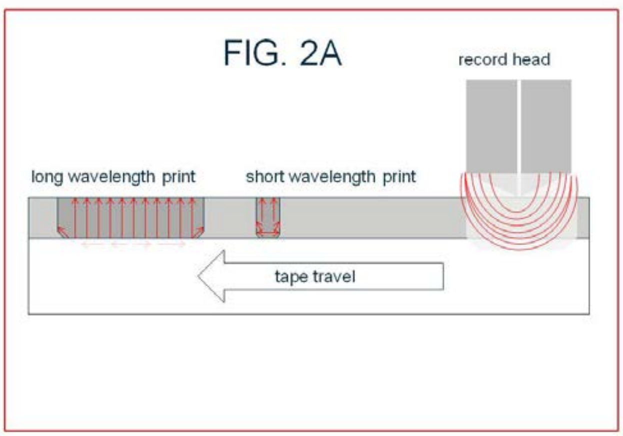


The first ferric oxide tapes made for cassette recorders began to lose their 6dB/octave increase at a relatively low frequency because the cassette tape moved much more slowly than open-reel recorders. The output increase dropped 3 dB at a transition point of 1,326.3 Hz, so the "equalization" decrease (B) was removed at this frequency. In electronic engineering terms, this transition point was achieved with "a time constant of 120 microseconds" (μs, one millionth of a second).

The chief reason for the decrease in output seen in FIG. 1A is spacing loss, which is a combination of losses due to surface irregularities and to the thickness of the magnetic coating. Although short wavelengths occur with increasing frequency and, therefore, produce more current in the playback head, short wavelengths begin to lose that output when the head begins to have difficulty reading them because the roughness of the tape and because the amount of magnetic energy they hold can no longer reach the head gap. Magnetic strength falls off exponentially as distance from the magnetic field increases, so even slight movements of the tape away from the head due to surface roughness will cause losses in output, and these losses are most apparent at short wavelengths. This effect is significant enough that tape manufacturers have been able to increase high



frequency output of some tape formulations by polishing the tapes through hard calendering during the production process without having to resort to changes in the coercivity of the oxide.

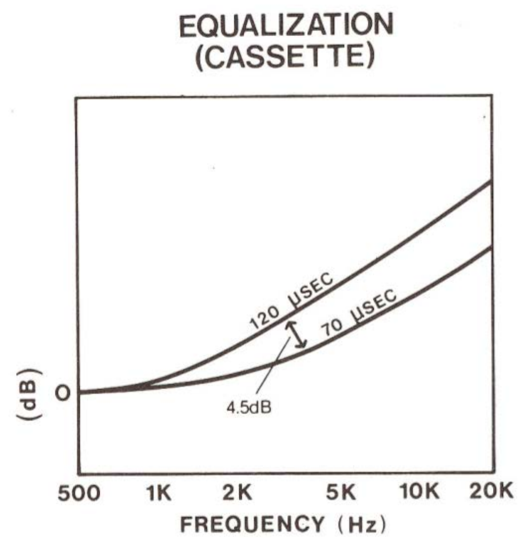


Loss in output due to the thickness of the tape is the other form of spacing loss. Magnetic output from short wavelengths is more effective closer to the surface of the tape because the short wavelength patterns deeper in the coating changed the direction of their magnetic patterns as they left the recording area of the record head. Although this is also true for long wavelengths, there is a much greater area of “correctly aligned” flux with the bigger magnetic patterns that long wavelengths produce than short wavelengths can produce (FIG 2A). The changed flux patterns deep in the coating tend to cancel each other out until they get closer to the surface. (Decreasing the bias during recording brings more short wavelength magnetic energy closer to the surface and reduces short wavelength loss due to self-erasure, but the bias reduction also reduces the penetration into the coating and results in lower output/higher distortion from the long wavelengths because less pigment is properly magnetized. Increasing bias magnetizes more pigment, up to a point, but also drives the short wavelength prints deeper into the coating and increases self-erasure with a reduction in high frequency output). Thinner coatings improve high frequency output, but at the loss of low frequency output. The standard coating thickness typical of cassette tape means that the playback head loses its ability to resolve short wavelengths due to spacing losses by 3 dB at 1,326.3 Hz, and that is why the downward equalization in FIG. 1B is removed at that point.

The invention of chromium dioxide tapes significantly improved cassette high frequency response with a totally new kind of tape oxide that was more efficient at short wavelengths than ferric oxide formulas. The uniformity of the oxide particles allowed smoother tape surfaces, and its higher coercivity allowed it to accept higher levels of high frequency energy. At the time of its introduction, however, the biggest complaint of the cassette as a music medium was its tape hiss.
Tape engineers decided to sacrifice the higher output or “SOL” (saturated output level) of chrome in order to reduce tape hiss. They decided to move the transition point of CrO_2 to a higher frequency of 2,273.6 Hz, or 70-μs EQ*. The time constant of 70-μs is advantageous because it allows the 6dB/octave slope (B) to continue longer and, in effect, “boosts” fewer high frequencies (FIG. 2); and less high frequency boost means less tape hiss gets boosted at the same time. The major audible difference between cassette

tapes is not in high or normal bias, but in 70- or 120-μs equalization: the 70-μs EQ will always provide about 4.5 dB less tape hiss. Chromium dioxide, chrome-equivalent, ferrochrome, and metal particle tapes all use 70-μs playback EQ.

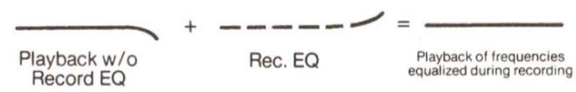
FIG. 2



There is another cassette playback time constant in addition to 120 μs and 70 μs that is not as widely known: 3,180 μs (50-Hz transition point). Instead of boosting the lowest bass frequencies so much that there may be problems with hum or low frequency noise, those frequencies below 50 Hz are rolled off slightly on playback. To make up for this roll-off, the record EQ gives those frequencies a boost during recording equal to the playback roll-off. Some manufacturers, however, are abandoning the 3,180-μs time constant standard because they feel that new head designs for better low frequency response are restricted by this time constant. A tape recorded on a machine with the 3,180-μs EQ and played back on a deck without it will have too much bass unless a tone control can reduce it to a degree.

Playback equalization is standardized so that any tape recorded on any one machine will sound the same on all machines when it is played back because all machines should have exactly the same playback EQ. Since the types of heads, circuitry, and tape formulations do differ, any adjustments are made to recording equalization or ‘pre-emphasis” in particular recorder using a particular tape. The adjustments are made to record EQ so that the frequency response on playback is flat according to the standard playback EQ that all decks follow (FIG. 3). All decks use some amount of record EQ to give the high frequencies a

FIG. 3



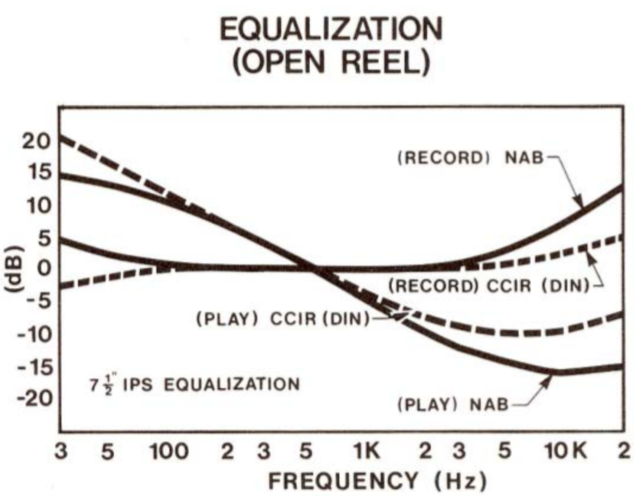
boost before recording because the high frequency losses cannot be compensated enough simply by removing the decreasing slope with playback EQ. Boosting the high frequencies before recording also avoids increasing the tape hiss that accompanies playback EQ, but the record EQ must not be so great that it boosts the highs to noticeable distortion or saturation caused by overloading the tape. So, while playback EQ is standard on all machines, each machine has an adjustable record EQ that is used to insure flat frequency response at the standard playback equalizations.

Open reel tapes also use equalization, and the faster speeds available mean less drastic frequency alteration. Complications arise, however, because of a variety of speeds and because of different standards—NAB, DIN, IEC, and CCIR. Most American and Japanese open-reel decks conform to NAB standards somewhat similar to those used in cassette decks. The chief difference between the NAB and the other, European, standards is that the NAB allows the 6dB/octave slope in playback to continue to a higher transition frequency to reduce more tape hiss, and the bass does not receive as much playback boost in order to avoid hum problems and low frequency noise. NAB standards call for a 3,180-μs EQ roll-off for the bass for 3 ¾ , 7 ½ , and 15 inches per second (ips); the high frequency time constant is 90 μs (1,768 Hz) for 3 ¾ and 50 μs (3,183 Hz) for both 7½ and l5 ips. At 30 ips there is no bass attenuation; 17.5 μs (9,095 Hz) is the high frequency EQ.

European standards, known as DIN (German), IEC (international), or COIA (French) use different time constants (FIG. 4). The 3 ¾ ips speed uses the same as those of the NAB, but other speeds have no bass roll-off at all. High frequency time constants are 70 μs (2,274 Hz) for 7½ ips and 35 μs (4,547 Hz) for 15 ips.

Some professional machines are designed so that a choice of NAB or IEC playback EQ is available. An open-reel recorder using NAB EQ uses a bass boost on record equalization to make up for the 3,180-µs roll-off on playback. NAB time constants also call for more record pre-emphasis of the high frequencies than the IEC time constants because the high frequency turnover or transition point occurs at higher frequencies to avoid more hiss (compare the 4.5 dB less noise of a cassette time constant of 70 µs compared to 120 µs). The drawback is that the extra

FIG. 4



pre-emphasis pushes the high frequencies closer to the point of distortion or saturation because of the boost. A 14,000-Hz tone will be boosted about 6 to 8 dB higher than a tone of 333 Hz at 7 ½ ips; 10-12 dB at 3 ¾ ips; and as much as 16-20 dB at cassette speeds. What musical content exists at such a high frequency generally has about 40 dB less energy than musical content in the midrange, but live music and high quality discs can contain much greater high frequency energy. When that greater high frequency energy gets an extra 16-20 dB boost, it can easily saturate the tape.

The change in the 6dB/octave slope to a less steep curve is determined by an electronic resistor- capacitor network built into a tape deck. The turnover frequency is determined by the formula:

$$\text{Frequency} = \frac{1}{2\pi T} = \frac{159{,}155}{\text{Time Constant Value}}$$

where T is the time constant in microseconds, and the Time Constant Value is an integral number such as 70 or 120. The time constant itself is determined by the values of the resistance multiplied by the capacitance in the R-C network. For example, a 10,000-ohm resistor X a 0.007-microfarad capacitor will provide a time constant of:

10,000 ohms x (7 x 10 farads) = 70 x 106 seconds = 70 µs

The seconds in microseconds refers to time. Resistance multiplied by capacitance results in units of time when all the other values cancel each other out:

$$\text{R} = \text{ohm} = \frac{\text{Mass x Length}^2}{\text{Time x Charge}^2}$$

$$\text{C} = \text{Farad} = \frac{\text{Time}^2 \text{ x Charge}^2}{\text{Mass x Length}^2}$$

$$\text{R x C} = \text{Time}_{seconds}$$

*When it became clear in the early 1970s that Dolby B noise reduction would become standard on all high fidelity cassette recorders, BASF engineers regretted the move to 70-µs equalization because Dolby NR reduced tape hiss by 10 decibels. If chromium dioxide tapes had stayed at 120-µs equalization and let Dolby NR take care of the hiss, chrome tape would gain back the 4.5 dB of SOL it sacrificed to reduce hiss.

That opportunity presented itself when chromium dioxide tape was adopted for high-speed tape duplication. BASF convinced A&M Records to release the Police's "Synchronicity" album on cassette for playback at 120-µs EQ. The unmatched low noise of BASF chromium dioxide tape with additional Dolby B noise reduction and increased SOL levels gave the tape a dynamic range that was very close to Type IV metal tapes using Dolby NR.