An overview of optimizing signal-to-noise ratio primarily in analog audio tape recording

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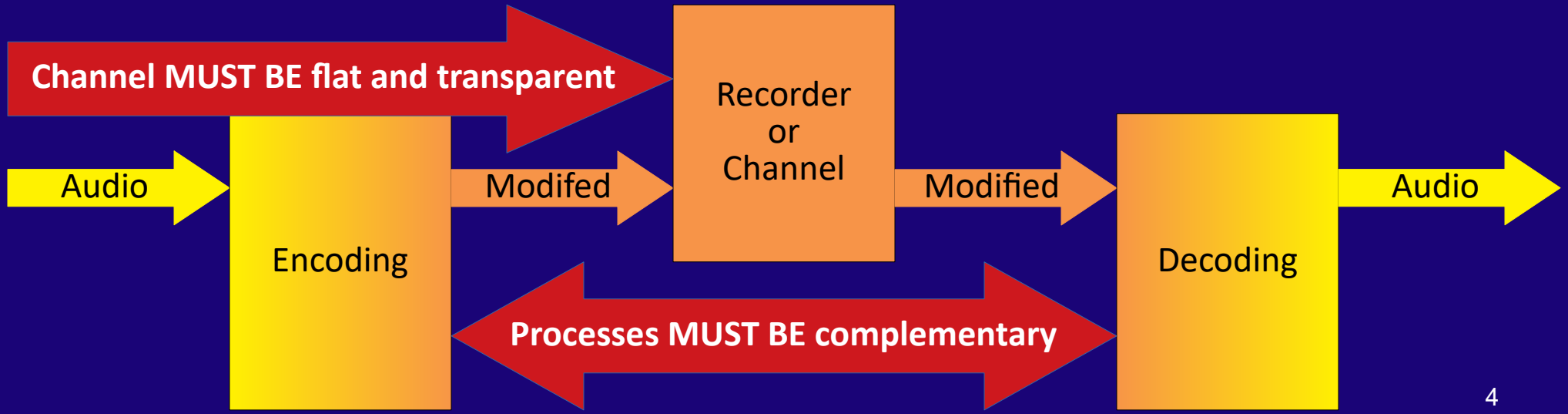
- Analog magnetic audio recording has always had a limited dynamic range
- Over the years four distinct pathways were used to improve dynamic range
  - Equalization
  - Improved tape performance
  - Two tracks per audio channel
  - Complementary dynamics processing
    Compression on record; expansion on playback
    COMpressor/exPANDER = COMPANDER

- The methods other than tape formulation changes involve a complementary process that must be reversed PRIOR TO SUBSEQUENT PROCESSING
- The integrity of the systems relies on the transparency of the recorder and the accuracy of the calibration and alignment of the overall system.

- My colleague John Dyson is convinced there are a large number of recordings being sold that were released without proper Dolby A decoding. I have confirmed that, in at least one case, it was intentionally done!
- EACH TRACK MUST BE PROPERLY DECODED prior to mixing or transferring to delivery media AND:



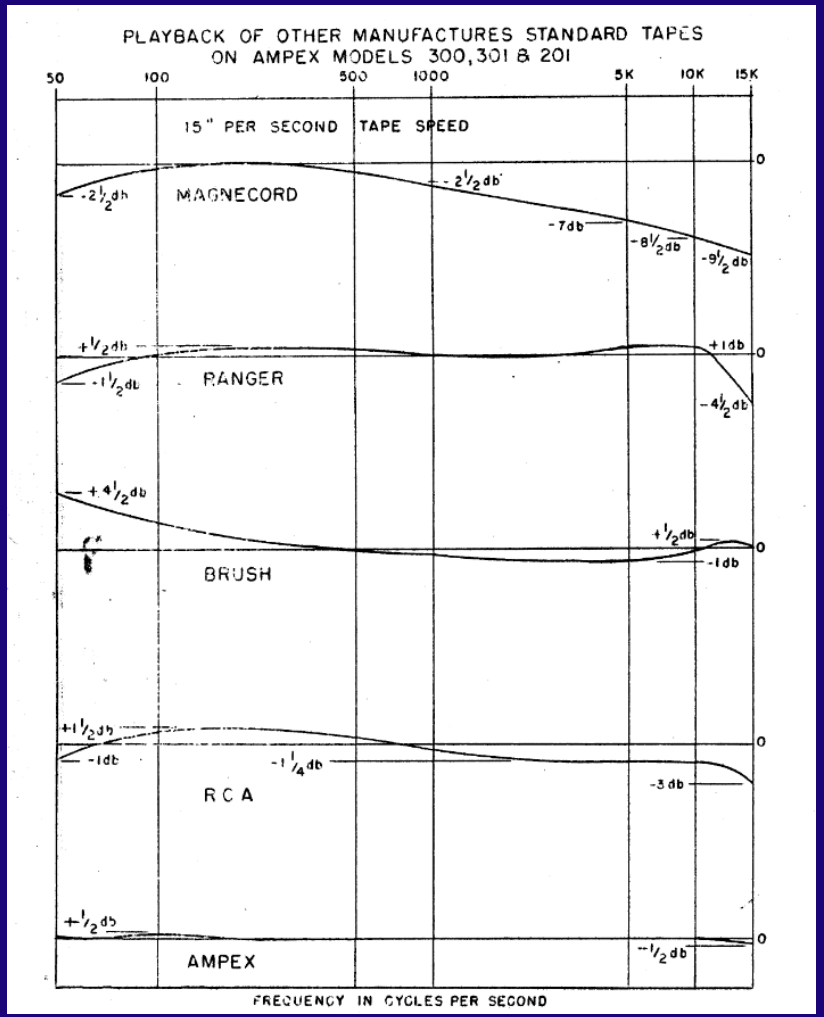
Equalization	Analog (1953-1981) IASA TC-04 5.4.10	Digital PCM-1 (1977), PCM F1 (1981), CD (1982) Optional (with status bit) 50 µs & 15 µs

- In 1948-49, Frank Lennert of Ampex improved the signal-to-noise performance of the tape recorder by modifiying the frequency response to better utilize the available dynamic range of the new Scotch 111 tape, building on work by the German Magnetophon engineers and Jack Mullin.
- IASA TC-04 lists 19 different standards that were published between 1953 and 1981. Nine of these are still in use today. **bit.ly/IASA_TC04_EQ**
- Early 14 and 16 bit audio recording systems developed in the 1970s, including the CD, used optional equalization (50 µs & 15 µs). Some (mostly digital) extraction methods do not compensate for this equalization and it must be manually corrected in post.

In 1953, the National Association of Radio and Television Broadcasters (NARTB, later NAB) adopted the reel tape standard.

Wonder why?

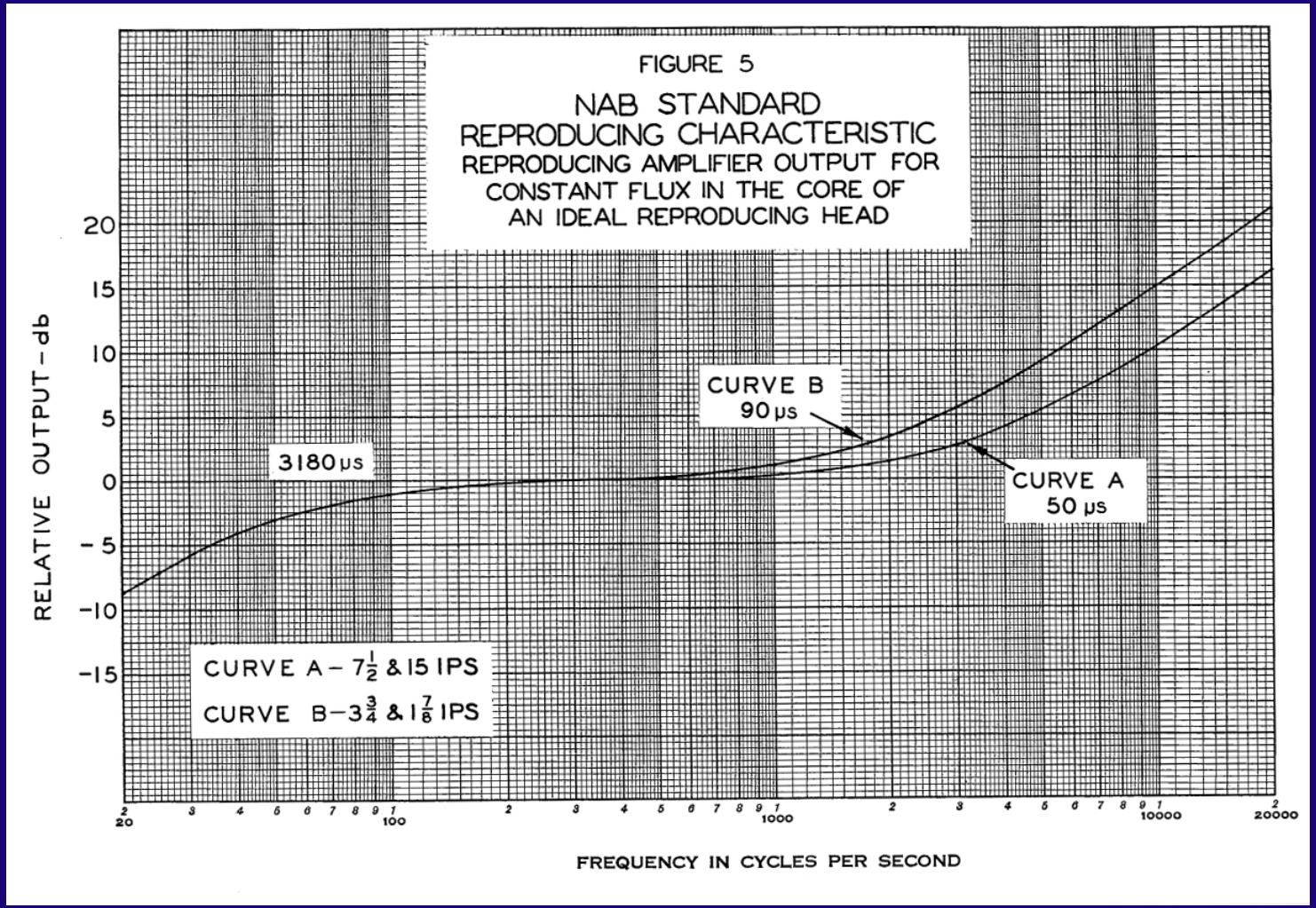
This is from circa 1949.



Ampex Model 201 Manual, c.1949

This NAB Reel Tape standard illustrates a typical playback EQ curve. This is a 1965 affirmation of the 1953 standard.

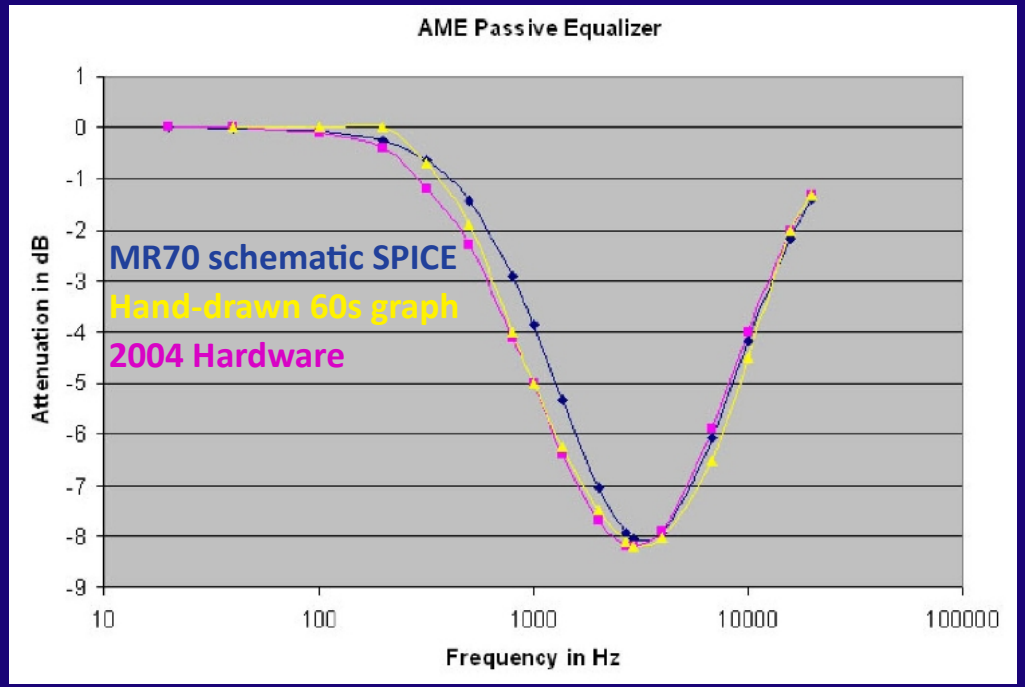
NAB Reel Tape Standard, 1965



Equalization	Analog (1953-1981) IASA TC-04 5.4.10	Digital PCM-1 (1977), PCM F1 (1981), CD (1982) Optional (with status bit) 50 µs & 15 µs

Special EQ	Ampex Master (1958)	Nagra Master (1968)

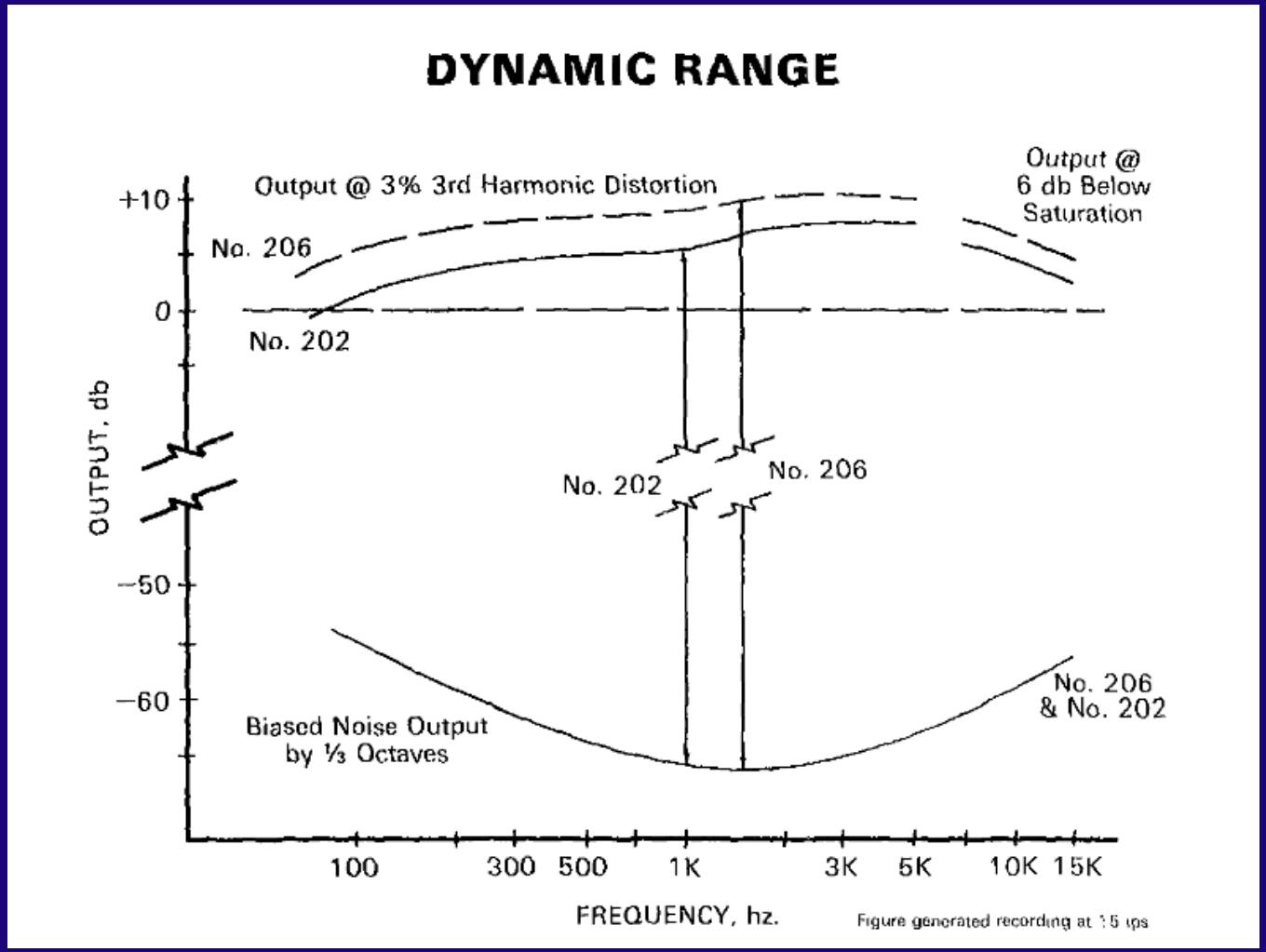
- In addition to the 19 standard equalizations, Jay McKnight of Ampex and Stefan Kudelski of Nagra created their own.
- AME boosted above the NAB curve on record and cut as shown on playback. It is the only curve requiring a separate outboard equalizer.



bit.ly/AME_Hess_2004

New Tapes | 3M 201-3 (1962) | 3M 206-7 (1969) | Ampex 456 (1975) | Ampex 499 (1991)

- There were several milestones where tape stock was modified to improve signal-to-noise ratio.
- Starting with 3M 111 (1949), each step targeted about a 3 dB improvement in signal-to-noise ratio from the previous generation.
- This became important as track counts increased. Noise increases by 3 dB with each doubling of the track count.
- Also, track widths were reduced, and noise increases by 3 dB for each halving of the track width.
  Example: 2” 16T@70 mils to 2” 24T@43 mils results in 2.1 dB more noise



Delos A. Eilers, 3M, AES Preprint 712, 1970

Multi-track

3M Dynatrack (1963-64)
Two tracks/channel, auto switch

Modern digital field recorders “backup recording”
One input to two channels with different sensitivities, select in post

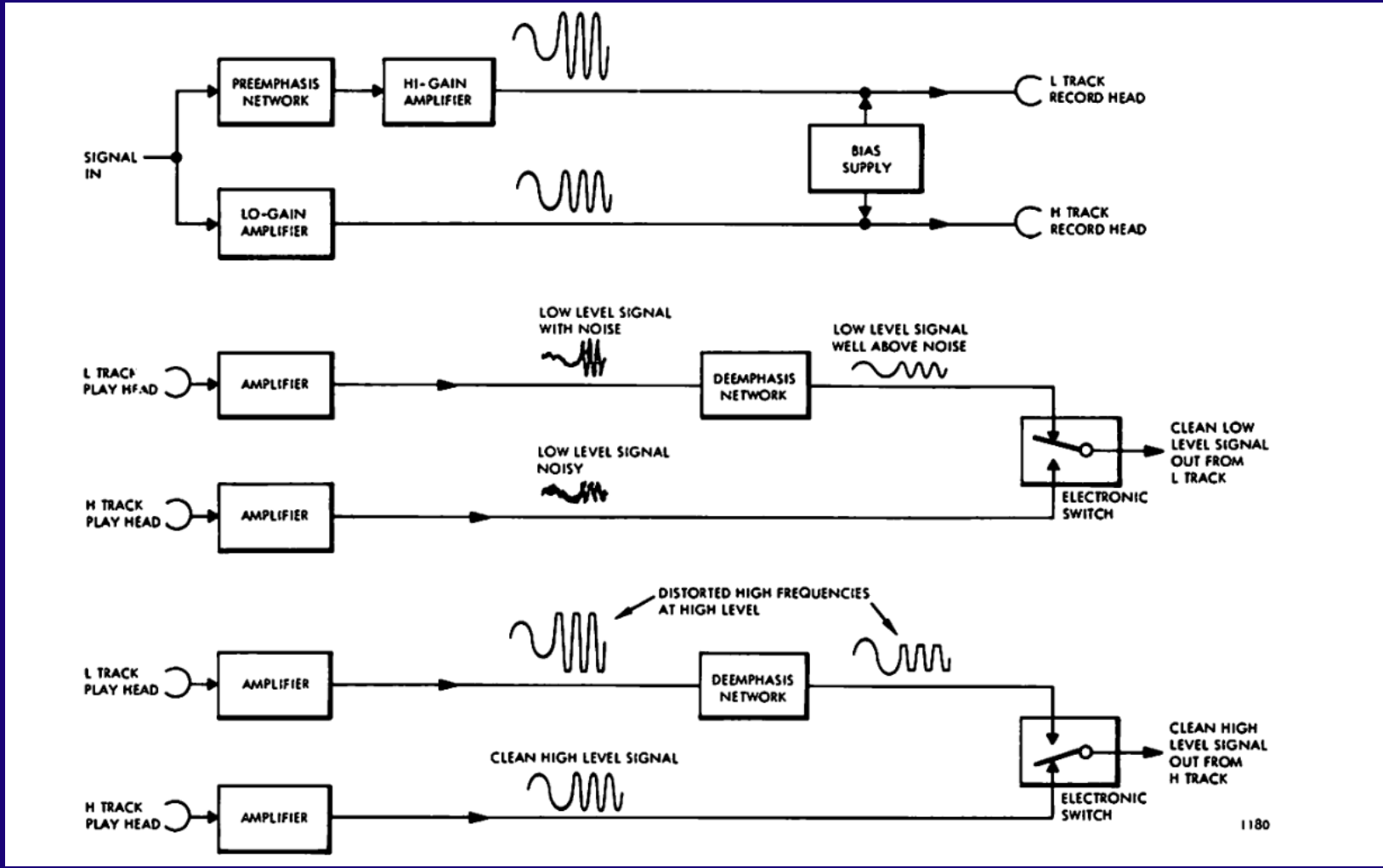
- Jack Mullin and Dale Manquen at 3M developed Dynatrack, using two tape channels recorded at different levels and equalizations. There was automatic switching as the signal increased during playback to transition away from the high-gain channel prior to its going into overload .
- While this was successful, the use of two tape tracks for one audio channel was not in keeping with the need for more tracks and lower costs.
- As an interesting aside, modern digital field recorders provide the option of “backup recording” where a single input is recorded on two channels. The sensitivity between the two channels is different, and the best take is manually selected in post. This, of course, is needed much less with 24 bit recordings!

3M Dynatrack

Signal Block Diagram

M23 manual (1969)

15 dB improve-ment in S/N ratio



- As more tracks were required for production and the overall noise level increased due the number of tracks and the decrease in track width, another solution was needed.
- In 1966 Ray Dolby (who had worked at Ampex on the 1956 VTR project) introduced a compressor-expander (companding) noise reduction system.
- In the 1980s and beyond, wider tracks (half-inch, two-track) and better tape formulations sometimes reduced the need for companding noise reduction systems, but high track counts suggested they were a good idea, at least for tracking if not for the final mix masters.

- Anything other than a proper decoder will degrade the original signal.
- Remember, a 24 track tape with all channels encoded requires 24 decoders to properly play it. One can digitize all the tracks at once and use a smaller number of decoders digital-to-digital, but it takes more time.

Always use *the proper expander/processor with* companander systems.

Pro Compander | Dolby A (1966) | dbx I (1971) | Telcom C4 (1976) | Dolby SR (1986)

- Dolby A is a four-band system providing only low-level processing. It offers a 10-15 dB reduction of added tape noise. Alignment level is critical.
- dbx I is a single band 2:1 decibel compander system that processes all levels. It offers substantially more noise reduction (on the order of 25 dB or so), at the expense of some audible artifacts. It has been embedded in some Tascam multi-track machines.
- Telefunken Telcom C4 is a four band system that claims to have better noise reduction than Dolby A and better transient performance than dbx I. Some knowledgeable users think it might be the best professional system.
- Dolby SR is more than a simple compressor/expander. It also contains level-dependent equalization.

Consumer Compander	Dolby B (1968) Clones: Ex-Ko (HU'74) JVC ANRS ('76)	dbx II (1971) Also LP records	Dolby C (1980) Also Fostex Multitracks	Dolby S (1990) Also Fostex Multitracks

- Dolby B is perhaps the most widely used system worldwide, provided on countless cassette and some consumer reel-to-reel machines for decades. There were two clones: Ex-Ko in Hungary and JVC ANRS.
- dbx II is not nearly as widespread but was used on a few LP phonograph records and a related version, dbx-TV, was used in the BTSC analog stereo television transmission system for the L-R signal on a subcarrier.
- Dolby C was added to many cassette decks and has more noise reduction than Dolby B, but is considered more sensitive to alignment errors. It is also used in Sony BetaCAM VTRs and early Fostex multi-track machines.
- Dolby S, derived from SR, was used in high-end cassette machines and late models (–S) Fostex multi-track machines.

Uncommon Compander

Burwen Noise Eliminator (1971)

Telefunken High-Com (1978)

Sanyo Super D (c.1982)

Systems with the lighter background are not in the author's collection.

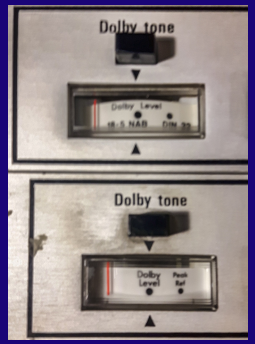
JVC Super ANRS (c.1978)

Nakamichi (Telefunken) High-Com II (1979)

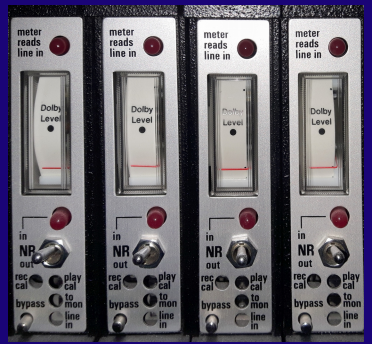
Toshiba ADRES (c.1982)

- Six additional companding noise reduction systems were available, but none achieved significant market acceptance.
- Burwen was a 3:1 decibel compander system but never sold—a non-issue.
- JVC Super ANRS is said to be better than Dolby C. Dolby challenged JVC's 1976 ANRS system for infringement. By the early 1980s, JVC licensed Dolby for their cassette machines, ending JVC's proprietary systems.
- Two single-band consumer versions of the Telcom system were available.
- Sanyo Super D was a well respected two-band system.
- Toshiba ADRES was a well respected two-band system.

Noise Reduction Processors for Telcom C4 and 5 different Dolby systems



Meters from two vintages of Model 361 Dolby A processors, approx 50 and 40 years old. **Align to the centre dot or equally bright green LEDs.**



The above Dolby units are close to 28 years old.

Meters from a 16-channel Dolby M frame for Dolby A, close to 40 years old.

In review, what does the restoration engineer need to worry about?

- Equalization is a major concern and needs to be correct. If a digital tape sounds too bright or dull, apply the proper EQ in post. Selecting which analog EQ can be more challenging. Metadata and source can be used to determine EQ, but listening must be used as well.
- Modern tape machines will allow adjustments for almost all common settings. Only AME requires an outboard box and there are instructions online at **bit.ly/AME_Hess_2004**.
- Tape types don't affect playback parameters (though carrier conditioning is a different topic).
- 3M Dynatrack is extremely rare. Perhaps noise gates could be configured to do the switching?

In review, what does the restoration engineer need to worry about in companders?

- One must learn to identify the types of companding. This can be accomplished through metadata, listening, and typical uses per format.
- One must maintain a proper library of companders. Two Dolby units can handle all five Dolby standards: 363 is SR/A with proper cards, and 422 is B/C/S with proper cards (note, S was a plug-in option card).
- The U-He Satin tape emulation plug-in provides a competent dbx decoder, although its Dolby A processing encouraged the current effort.

Status of hardware decoders

- Dolby A and SR decoders are available on the used market. The Model 363 was introduced in 1988 and was available until the late 2000s. It is out of production.
- Dolby B, C, and S (if you have the S option board) are available on the used market. The model 422 was introduced in 1990 and was available until the late 2000s. It is out of production.
- dbx and Telcom units are generally available.
- dbx made the K9-22 card and Telcom made the C4D card, both of which work in frames designed for Cat 22 cards.
- The Dolby Cat 280 SR card (another Cat 22 plug-in replacement) is generally inferior to the 363 for SR reproduction. At this point the SR multitrack frames are also preferred over the Cat 280s, but this needs further investigation.

Moving forward, it seems that a software decoder is the ideal approach.

- It would not be subject to degrading components or loss of calibration.
- It retains an all-digital workflow.
- John Dyson and I (DH) currently have a very competent software decoder that while not licensed by Dolby can play Dolby A encoded tapes. Phase 2 should happen, we'll have to see about phase 3.

Phase One (4Q 2018) (Working now) DH Decoder mode: DA (GUI early 2019)	Phase Two (2019) (Probable) DH Decoder modes: DB, DC, X-I, X-II, C4	Phase Three (2020) (If possible) DH Decoder modes: DSpR, DS

These are not currently under consideration for inclusion in the project:
Burwen Noise Eliminator, JVC Super ANRS, Nakamichi (Telefunken) High-Com II, Sanyo Super D, Telefunken High-Com, and Toshiba ADRES, though if there were a need, we would consider it.
Ex-Ko and JVC ANRS should decode with the DH Decoder in mode DB.

Features of the Dyson-Hess Noise Reduction Decoder System (DHNRDS)

- DA provides reduction of NR-induced intermodulation distortion
- DA provides options for potentially compensating for bad recording units
- DA provides ability to use non-standard modes (e.g. HF0+HF1 only)
- GUI planned to run batches after setting calibration levels for each file
- Runs under Windows, no special requirements other than fast PCs
- Multi-standard (6 likely, 8 possible)
- Broadcast Wave Coding History Update

DECODER INFORMATION **www.DHNRDS.com**

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Reminders

- Many music releases, including the original, suffer flaws and are different from each other. Use caution when selecting a reference.
- As audio engineers working with archival material, we have the responsibility to make certain that at least the following are properly adjusted for each recording:
  - Tape head azimuth
  - Tape equalization
  - Tape speed / pitch
  - Proper noise reduction
  - Audio levels

Thanks to Don Ososke and John Dyson for their assistance and review

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