Tape vs. tape emulation

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Introduction

Magnetic tape is becoming a thing of the past in most studios, but it is still revered for its classic analog sound. Magnetic recording has a history of a hundred years and tape had its own role in World War II. Through the years, the mechanics of tape have slightly changed and improved. With new technology, magnetic tape is finding its way inside of plugins for popular recording programs. Tape machines are now being emulated to provide a cheap, more portable, and more reliable solution to the analog tape machines of yesteryear. Tape still holds a place in many experienced engineers’ hearts, but the manufacturing of tape machines and tape has now dwindled down to a low demand.

The History and Journey of Magnetic Tape

The beginnings of magnetized tape go back to 1898 when a Danish inventor, Valdemar Poulsen, created a device called the Telegraphone. The Telegraphone was a device that used steel wire as a magnetic support that would slide across an electromagnet (SoundFan, 2007). By 1900, Poulsen made a name for himself and was dubbed “The Edison of magnetic recording.” Poulsen went on to invent more mediums of recording like solid steel tape and metal discs (Hammar, 1982, p.2). Poulsen went on to have many marketing failures, and the idea and medium never truly took off. The idea of magnetic recording lay silent in the United States until 1939 when Marvin Camras built a new wire recorder that used AC current instead of DC current. The results were far less distortion and a better signal-to-noise ratio (ibid.). The Allied Forces, in much of World War II, then utilized this machine.
WWII is an important subject when discussing the emergence of magnetized tape because it was Germany that had the upper hand. In the pre-war time of the late 1920s, Fritz Pfleumer, built the world’s first tape recorder. Pfleumer had made paper strips that were coated with carbonyl iron particles suspended in lacquer (ibid). Tape recorders now had a future and were invested by AEG-Telefunken from Berlin and marketed the machine under the name “Magnetophon” or “magnetic phonograph” (Hammar, 1982, p.3).

In 1936, German radio stations unified into a network called Reichs-Rundfunk-Gesellschaft, or RRG, that were all interconnected by a series of underground audio lines. A year before Hitler came to power, Germany had adopted wax and lacquer discs. In 1938, H.J. von Braunmuehl adopted magnetic tape for the future of German broadcast. By 1941, two years into WWII, all German radio stations were equipped with AEG Magnetophon tape recorders. Around 1939-40, Walter Weber of the RRG accidentally found that AC-bias current dramatically increased fidelity in tape recorders, much like Camras in the U.S. The difference was substantial, whereas DC-bias Magnetophons had a frequency response of 50 Hz to 6 kHz, 5 percent distortion and a dynamic range of 40db, AC-bias gave a frequency response of 40 Hz to 15 kHz, only 3 percent distortion and 65 dB of dynamic range (Hammar, 1982, p.3-4).

In 1936, AEG-Telefunken brought a Magnetophon, in secret, to General Electric in Schenectady, New York, to convince American marketers to sell the German tape recorder in the U.S. The Magnetophon was still on DC-bias and because there were no engineers present, to the marketer’s ear the sound was no
better than lacquer discs or wire recording of the time. It was not until 1942 that Major John (Jack) T. Mullin of the U.S. Army Signal Corps began to have curiosity about the high fidelity, 24-hour RRG broadcasts. By 1942, Germany had been broadcasting on tape for almost ten years, and because it was so mundane for them, they had never classified their high fidelity, AC-bias tape machines. No information about them was relayed to the U.S. and little was known about how Germany had such a high fidelity medium of recording and broadcasting. In July of 1945, two months after the Victory in Europe Day, Mullin was amazed to discover American GIs casually using the tape recorders in Bad Nauheim, Germany (Hammar, 1982, p.4-5).

Now a civilian, Mullin sent many parts, pieces, and tape back home with him to San Francisco in 1945. Mullin was sure that Germans and companies with connections to Germany would start to introduce a high fidelity tape recorder to the U.S., but nothing happened. In May of 1946, Mullin gave a demonstration of his Americanized Magnetophons in San Francisco at a convention held by the Institute of Radio Engineers, or IRE (now known as the IEEE). Future Ampex employees and innovators saw this demonstration. Ampex was a company founded in 1944 to build small radar motors and generators for Navy contractor Dalmo-Victor. By 1946, Ampex had decided to build America’s first mass-produced professional tape recorder for the United States (Hammar, 1982, p.6-7). By 1949, Ampex had made 112, 200-Series Tape recorders that cost about $4000 dollars each.

Around the late 1940s, tape found its first commercial application in the United States: radio rebroadcast. It was the great Bing Crosby Show that first
utilized Ampex machines for the purpose of rebroadcast. A deal was made in 1946 with Bing Crosby, ABC, and Ampex for the use of the machines for the 1947-48 season of the show. Mullin became the chief engineer for the show, and it became a huge hit. What also came out of this deal was Bing Crosby's investment in Ampex for $50,000. This was the start of Ampex growing from a six-employee company to developing into one of great Silicon Valley companies (Hammar, 1999). Ampex soon came out with two- and three-track recorders. Through the next decade, Ampex would continue to grow and start to revolutionize recording.

In 1953, Ross Snyder of Ampex was sitting in his office in Redwood City, California, when he came up with the idea of selective synchronous recording, or sel-sync. The two- and three-track multi-track recorders of the time were labeled “sound on sound,” which referred to a process we now consider to be destructive recording. If one track was prerecorded and you wanted to record using the next available track, it would record over what you had prerecorded. This “sound on sound” technique was not thrilling to most people. After layering multiple tracks on top of each other, the sound began to degrade tremendously with distortion, noise, hum, and overuse of the physical tape (Peterson, 2005).

The Sel-Sync process that enabled overdub multi-tracking required several systems to function as one and it was a difficult procedure to invent. The team at Ampex started working on it and successfully created a one-inch, eight-track sel-sync machine. Ross Snyder was not the only one thinking about this idea; Les Paul had it on his mind as well. The first of those machines was sold to Les Paul for $10,000 and he made use of them with future recordings. The idea of overdubbing
on tape was revolutionary but was hardly noted at the time. Snyder recalls his expectations:

I thought the market would be confined to a few dozen at the absolute most.

After all, how many people are doing professional recording by way of overdubbing? Not many, but those who did needed it badly (ibid).

Ampex’s attorney said it was obvious engineering and the technology could not be patented so the only thing Ampex did about the new idea was patent the “Sel-Sync” name, but the concept would be used throughout the future and is an integral part of recording today (ibid).

The multi-track recorder was now available, and many companies besides Ampex started to join in creating these recorders. However, not many studios were quick to jump into the world of multi-track recording. Tape recorders started to be seen in studios in the early 1950s but were not truly adopted until the mid 1960s. As soon as people began to hear the clarity, better frequency response, and lack of noise and distortion on tape, they were adopted over the wax and lacquer discs. Tape also brought convenience not previously had like ease of editing takes, overdubbing, and multi-channel recording. Between the 1960s and the 1980s nearly every single recording you heard came was tracked, mixed, and mastered to reel-to-reel tape.

**Tape Machines and Manufacturers**

Ampex was a powerful company in the world of tape recorders. As previously mentioned, the Ampex 200 series recorder was one of the first
commercially used tape machines available in 1949. There were many that followed it as well. Ampex had a run of tape machines from the 200 series in 1949 up until the late 1970s. They started with the 200 series in 1949, the 300, 400, 500, and reissue of the 300 series in the 1950s. In the 1960s, Ampex released VR and AG series recorders. The AG series, which ranged from two to eight track counts, were considered the workhorse of magnetic recorders. In 1976, the world was introduced to most well known model: the ATR-100 series tape machines, which are still used today. These tape machines were utilized for mastering purposes (Sanner, 1999). This machine was utilized so heavily it is said that “it would be easier to list classic albums that weren’t mixed down on this machine, rather than try to list all that were” (Studer, 2013). Studios still use this machine today to master stereo mixes of albums to tape. Prominent plugin manufacturer Universal Audio has also made an emulation of the Ampex ATR-102 to use as a plugin within their software suite (Universal, 2013a).

Ampex was not the only one company selling tape machines. By the 1960s and 70s, many companies had their own variations. One company in particular that is still well known today is Studer. Studer started as a small company in Switzerland in 1948 building oscilloscopes (Studer, 2013). Soon after their founding, Studer began to import tape machines from the United States and replicate them to their own standards. In 1949 Studer started to make their first tape recorder (ibid). In the 1950s, Studer made one and two channel machines, the A37 and B37. In 1963, Studer made a fully transistor tape machine, the A62. In 1964 Studer introduced their first 4-track machine, the J37 (ibid). In 1970, Studer came out with their A80
model, and it featured a sturdy tape transport, electronically controlled tape tension, electronic tape timing, and electronic speed control. In 1978 Studer introduced the famous A800 tape recorder that featured a microcomputer-powered drive (ibid). The Studer A800 is still used today and has also been emulated in Universal Audio’s suite of plugins (Universal, 2013a).

The 80s marked a transitional period for tape recorders. As new mediums of recording started to make their way into studios, the production of tape recorders started to decline. The expense that came with buying tape soon became too much for studios and many decided to save money in the late 80s by moving to digital mediums such as DAT, or Digital Audio Tape, and ADAT, Alesis Digital Audio Tape. Not all studios made the transition because not everyone preferred the new digital sound. Many studios did not initially ditch their tape machines for digital, but by the mid-90s analog tape recording became less substantial. The sound of tape still remains in studios today but on a much smaller scale.

**The Mechanics of a Tape Recorder**

There are many parts and pieces that are involved in tape recorders. Many of the traditional parts that were part of the early recorders were still utilized until the end of the production of tape recorders. It was not until the 1970s when microprocessors were introduced into tape machines that they became more technologically advanced.

The first thing to discuss about tape machines is the medium of tape itself. Tape is basically magnets on top of strips of paper. The paper base layer is made up
of a polyester such as polyester chloride, or PVC. On top of the PVC is magnetic oxide and in this material are tiny magnets called domains (Runstein, 2012, p.96). The domains each have polar sides, and demagnetized tape has all the domains opposite each other (Runstein, 1974, p.80). As tape passes through the machine sections are magnetized to several different polarities and intensities as it passes (ibid).

Magnetic tape has different widths and those widths determine how many channels it can hold. Tape widths can be ¼”, ½”, 1”, or 2”. Mono and stereo tape recorders use ¼” tape; four-channel uses ½” tape; eight- and twelve-channel use 1” tape; and sixteen- and twenty-four-channel use 2” tape.

A tape recorder utilizes three heads to record, playback, and erase tape. A record head has two metal poles wrapped in wire that create a magnetic flux between a gap (ibid). The record head receives electric current that alternates, and the constant changes in amplitude alter the flux between the gap. As the tape passes the gap where the flux lies, the magnetic polarities change orientation. A bias current, or a high-frequency current, is also fed through the record head to minimize distortion (ibid).

The playback head is constructed similarly to the record head but the pole pieces do not create a flux (ibid). Instead, the pole pieces induce the flux created on the tape after being passed by the record head. The resulting current is then amplified. The erase head sends an alternate and higher frequency bias current that randomizes the domains and brings the magnetism of the tape back to zero (Runstein, 1974, p.81).

Tape can be recorded and played back at different speeds. The speeds are
denoted by ips, or inches per second, and the most common speeds used are 7 ½ ips, 15 ips, and 30 ips. Higher tape speed and decreased gap size in the poles of the record head enable higher frequencies to be recorded and played back (Runstein, 1974, p.92).

Tape is recorded and played back from left to right from the supply reel to the take up reel. The tape is threaded through tension arms, a capstan and pinch roller, guides and the three heads in the order: erase, record, playback. After the three heads, the tape continues through another guide and tension arm to the take up reel (UCSC, 1996).

Each channel on tape recorders has modules that include more settings and functions that calibrate the machine and can be used to customize the sound of the machine. EQ for both the record and playback amplifier can be adjusted to provide a flat or more favorable frequency response (Runstein, 1974, p.86). Both the Ampex AG-440 and Ampex MM1000 contain the same three modules with their configurable parameters. The bias module gives you control over the bias control, the erase adjustment, and the bias adjustment. The record card lets you adjust the record calibration, high-speed calibration (for 15ips), and low-speed calibration (for 7 ½ ips). The reproduce module gives you a low EQ and high EQ adjustment for the low and high speed (Ampex, 1969). These parameters are there for when the machine needs to be calibrated and aligned to a specific reel of tape and should be checked constantly to ensure that every recording session is going to sound identical.

Five characteristics about tape that give tape some of its sound are wow,
flutter, scrape flutter, drift, and noise. Wow is a frequency modulation between 0.1Hz and 10Hz, and flutter causes frequency modulation between 10Hz and 100Hz. Wow and flutter are typically caused by mechanical irregularities within a tape recorder. When tape is not passing through the three heads at a very constant speed, wow and flutter are introduced into the recorded audio. Wow effects the low frequencies of audio and flutter effects the high frequencies. Wow and flutter can be measured in root-mean-square, or RMS, or in a peak-to-peak value over a specified amount of frequency bands (Talbot-Smith, 2001, p.3-17).

Drift has a modulation rate below 0.1Hz and occurs when tape being recorded across the heads from one reel to the other does not move at the same speed. This can result in waveforms either slowing down or speeding up at small increments. The pinch roller not accurately spinning at a consistent speed can cause drift. Scrape flutter has a modulation rate between 1kHz and 5kHz and results from the tension in the tape as it moves from reel to reel. The tension arms give tape tension so that it can smoothly move across the three heads. This tension between the record or playback head and the tension arm can create resonant vibrations much like a guitar string vibrating back and forth (Robjohns, 2010).

Noise is another characteristic of analog tape recording that is inherent in all recordings. The noise that comes from tape is a “hiss” that is a result of the “random variations in magnetization from the oxide granules” that will give a high frequency noise (Nave, 2013). Noise reduction processes were utilized to reduce the amount of tape hiss. The DBX Noise reduction system was used to minimize this hiss by compressing incoming signal to be recorded to tape and then expanding that signal
upon playback to increase the dynamic range and keeping the noise floor at the lowest level of the range as possible (ibid) (see figure 4).

**Tape Machine Costs and Upkeep**

A tape recorder itself is an investment and the cost of a reel of tape is one of the large costs associated with use. Today, few manufacturers continue to make tape that can be used for studio tape recorders. Because of the low demand in today’s digital age, tape costs have risen.

The cost of the tape alone sways people into using a substitute like tape emulation plugins. Quarter inch tape is the cheapest out of the few formats but starts at $65.00. A half-inch roll of tape costs around $100.00, and a two-inch roll of tape will cost a little over $300.00 (Full, 2013). The cost effectiveness of tape versus digital is also worth mentioning. A 2500 foot roll of tape, at the afore mentioned prices, recorded at 15 inches per second will give you 33.33 minutes of recording time. In the digital domain you can buy a terabyte hard drive for approximately $60.00 to $150.00 (Amazon, 2013). With this terabyte hard drive you can record one audio track, at 24-bit depth with a 48-kHz-sample rate, for up to 202 hours of audio (Sound, 2013).

Manufacturing has been decreasing for many years now. Companies have ceased or sold off their tape manufacturing. Quantegy Inc. was a large name in the tape-manufacturing world and produced tape up until 2007 (Quantegy, 2007). Recording Media Group International, or RMGI, is one of the only companies still in existence to manufacture reel tape. Their base of operation was in Oosterhout,
Netherlands, but the company was purchased and taken over by Pyral in 2007. Pyral now operates their tape manufacturing in Avranches, France (RMGI, 2011). The only company left in America to produce reel tape is ATR Magnetics in York, Pennsylvania (ATR, 2013).

Tape machines require constant attention with daily, monthly, and yearly upkeep. The sensitivity, output level, bias requirements, and frequency response of different kinds of tape require the constant calibration of the record level, playback level, bias current, record EQ, and playback EQ (Runstein, 1974, p.90). It is because of the constant upkeep, calibration, competition from digital media, and the rising costs of tape that recorders are being used less and less.

**Tape's Use Today**

Today's digital age has brought in new technologies that are favored by many studios. While some studios implement these new technologies alongside the analog realm of recording, many new home and commercial studios are completely digital. Depending on the studio and their budget, they may or may not implement analog recording tools.

Smaller studios simply cannot afford the ever increasingly expensive analog world of recording. With large recording consoles selling between $25,000 and $150,000, it is not easy starting a large-scale studio. For smaller scale operations, there are more digital consumer options. Digital Audio Workstations, or DAWs, and a simple interface that connects to a computer are all that is needed for a basic, all-digital home studio.
Many small studios will use predominantly digital equipment. Spirit Vision Studios in Carmel, CA, has an all digital recording setup. Spirit Vision records on an Apple iMac computer, through a Focusrite interface connected through FireWire, and mixes completely in the digital domain. They have a small selection of outboard preamps, but otherwise everything is completely digital. Small studios like Spirit Vision commonly use plug-ins to emulate the sound of analog equipment (Spirit, 2013).

A medium-size studio, like Tiny Telephone Recordings in San Francisco, CA, is more likely to have a mixture of analog and digital recording tools. All medium-size studios are going to have a medium-to-large-format console, a large amount of outboard processing gear, lots of microphones, and preamps to go with them. Medium-size studios are more likely to use tape. Tiny Telephone prides itself on being an analog recording studio with the exception of recording on a digital medium. Minus the digital medium to record on, all the signals are being tracked through, processed on, and mixed using analog equipment. The tape side of Tiny Telephone is in their mix down process after a mix is complete and they want to add a touch of tape sound. A small portion of material might be fed through the tape machine in the mix process for creative purposes as well (Tiny, 2013).

Larger, high-end studios like EastWest Studio in Los Angeles, CA, have sizable collections of both digital and analog equipment. EastWest utilizes all of their analog equipment while recording in digital but also has the ability to fully record to tape. EastWest features a Studer A827, which can record twenty-four channels of audio onto two-inch tape. This studio also has an Ampex ATR-102 and an ATR-124 for
mastering purposes. EastWest can record, mix, and master all on tape. If mastered to vinyl, the whole signal path of an album could be completely analog without touching digital systems. (EastWest, 2013)

Most commonly today, tape is utilized as an effect or in the mix down process. For most studios it is feasible to own and operate a simple two-track or four-track tape machine. This can be used to either put digitally recorded material through or to simply record to tape and then bring it back into the digital realm. In mix down, studios will commonly export audio stems or a final stereo mix of a song to add an analog touch. Mastering also caters to the tape enthusiast with the ability to master with digital or analog equipment. If an engineer records in analog and wants to keep the signal chain digital-free, many mastering studios have the necessary tools to keep the signal analog all the way until it finds its way onto CD.

**Reel Tape in the Digital Domain**

With the convenience and low cost of plugins, reel tape has found its way to DAWs everywhere. There are quite a few companies that emulate and replicate the sound of tape. It takes skilled ears and minds to figure out how to translate the sound of a tape recorder into a digital language. This language is then put into a clear and easy interface that we call a plugin. A few tape plugins are simple, to the point, and offer a taste of tape. Other manufacturers of tape plugins go all in and try to bring the exact sound of tape directly to digital users.

Companies like Waves, Universal Audio, Avid, Slate, and Crane Song all are heavily invested in tape emulation plugins. Waves has two tape plugins: the Kramer
Tape plugin that models an Ampex 350 with model 351 electronics and Abbey Road Studios J37 Tape that models a Studer-built and Abbey-Road modified J37 tape machine (Waves, 2013a) (Waves, 2013b). Avid offers a suite of plugins that bring tape sound to digital workstations. Of the three plugins, the Reel Tape Saturator combines modeled characteristics of the Studer A800 and the 3M M79 tape recorders (Avid, 2013). Crane Song’s Phoenix II is from a smaller company that enables users to recreate a variety of tape emulation sounds (Sweetwater, 2013). Slate is a newer company that recently released a tape emulator plugin called the VTM, or Virtual Tape Machine. The VTM has been modeled on “world-renowned recorders” such as a nameless ½-inch, two-track mastering recorder and a 2-inch, 16-track machine (Slate, 2013). Finally, there is Universal Audio, which is among the most popular of plugin makers to emulate tape. Universal Audio prides itself on being incredibly close to the reproduction of two machines by closely working with the actual manufacturers and taking apart and studying each machine. Universal Audio has one plugin dedicated to the Ampex ATR-102 recorder and another that emulates the Studer A-800 recorder (Universal, 2013a).

The process through which a plugin is made is a very scientific and computer-intensive operation. There are two possible routes to take when looking at a piece of gear such as a classic tape machine for emulation. The first route is to “pass a variety of static and changing signals through the device, measure the input-to-output characteristics for all front-panel settings, and then develop DSP [digital signal processing] code that accurately emulates those changes” (Lambert, 2010). The second way would be to “examine the circuit diagram and model the various
component blocks” inside software “to generate a transfer function from input to output.” These generated functions “can then be used to generate DSP routines that emulate the device in question” (ibid). Most companies will employ both techniques, some tweaks, and many listening sessions to determine what changes need to be made.

David Berners of Universal Audio has said “analog equipment that exhibits high-bandwidth, non-linear behavior presents the biggest challenges...but it’s often the sound of these non-linearities that makes the original analog equipment so desired” (ibid). A tape recorder, in particular, has many non-linearities due to the age and mechanics of the device. The signal-to-noise ratio of a Studer A800 is going to be different from an Ampex ATR-102, while the drift on an Otari MX5050 is going to be different from an Ampex AG440. The wow and flutter from two different machines of the exact same model will even vary.

When it comes to the tape plugins themselves, there are many parameters to manipulate depending on which plugins you are using. A few tape plugins are relatively simple and provide you with a few controls, but there are others that try to give every control imaginable. Two examples are Avid’s Reel Tape Saturation and Universal Audio’s ATR-102 plugin.

The Reel Tape Saturation plugin (figure 5) from Avid is rather simple. The plugin gives you about 6 knobs and a few other features to help simulate tape. The first knob is ‘Drive,’ which allows control of the amount of saturation effect. There is a tape machine selector, which switches between the characteristics of either a 3M M79 machine or a Studer A800. The user can also adjust the tape formula with
either 'Classic,' which has the characteristics of Ampex 456 tape, or 'Hi Output,' which is the characteristics of Quantegy GP9 tape. Avid also includes a knob to adjust the speed for 7 ½, 15, and 30 ips. There is a noise feature that can adjust the level of noise present in the signal. A 'Cal Adjust' knob is available that simulates the different calibration levels of tape machines for +3db, +6db, and +9db. Lastly, there is a 'Bias’ knob that can simulate the effect of over-biasing or under-biasing a tape machine when it is calibrated (Digidesign, 2012, p.339-340).

Universal Audio’s ATR-102 plugin (figure 6) has quite a few more controls than the Reel Tape Saturation plugin by Avid (Universal, 2013b). The ATR-102 starts with having its own input, output, and signal path selection so you can put audio through the ATR's Input without touching tape. Then there is Sync, which goes through all the electronics, to tape, and is played back from the record head. Last there is Repro, which is the audio coming off of tape that is played through the repro head of the unit. There are four speeds of 3 ¾, 7 ½, 15, and 30 ips with head widths of 1/4”, ½”, and 1”. There are four types of tape formulas that include Ampex 250, 456, 900, and GP9. The plugin has calibration controls to switch between +3, +6, +7.5, and +9 dB operating levels. The ATR provides two different EQ settings between NAB and CCIR, which are the American and European standards. There is a Bias control, a High Frequency EQ, a Shelf EQ, Repro High Frequency EQ, and Repro Low Frequency EQ, which are all faithful to the ATR unit. There is a noise control, a wow and flutter on/off button, a crosstalk on/off button, auto-calibration, a transformer on/off switch, switchable metering, and a bypass function. The ATR-102 plugin also features a way to calibrate the plugin as you would the actual
physical model. If an engineer has a specific way of calibrating and aligning tape machines, they can very well do so right inside the plugin with bias controls and a list of test tones (ibid).

It seems that Universal Audio covers every aspect and control of the ATR-102, but there are a few things about the plugin that you cannot control via the physical machine, which makes the emulation a little different. The ability to enable and disable crosstalk, wow and flutter, and noise is not something that comes on the physical model. On a real ATR-102, one cannot simply adjust the amount of noise, wow and flutter that exists in the machine; those are some of the non-linearities that exist in that specific machine. The thing about plugins is that they will sound exactly the same every time you use them and that does not happen when it comes having a physical tape machine. Tape is also an irregularity that cannot be restricted by a plugin. Tape can greatly differ between different types of tape, but tape can also slightly differ even between batches of the same tape. With this plugin, one will get the same tape sound every single time, and that can be a good and bad thing. The reasons to use tape emulations continue to stack, but there is still a discussion to be had about what the emulations cannot emulate: the authentic sound of audio passing through transistors, transformers, tubes, wiring, metal, tape, preamps, and the many other electrical aspects and components of a real tape machine.

The Analog World

The analog side of recording has been decreasing since the emergence of digital recording, but it is not just tape that influences the sound of “analog warmth.”
This “warmth” is highly coveted, and without an analog signal chain of equipment there has been a need for and a creation of digital emulations to bring warmth back to digital recordings. From microphone, to preamp, to console, to outboard effects and processing, to tape, and all the tubes, transformers, and hundreds of pounds of metal that this electric current flows through, all parts of the signal chain share a part of the sound that people call “analog warmth.”

The choice of microphones is the first part of the signal chain that can add warmth or character to a sound. The frequency response of the microphone, and whether it is a condenser, ribbon, dynamic, or tube, will all in part give some sort of character to the recorded audio. The preamp chosen, whether it is a solid state or tube preamp, the condition the preamp is in, and the amount of signal fed to the preamp, again, can add a warmth or character to the sound.

Tubes and transistors are also part of the analog warmth world. Overdriving tubes and transistors gives off different characters and distortions. The amount of power being fed to the tube or transistor depends on the amount of signal coming in, and the result of the output can be given that character or distortion.

One thing to understand is harmonic distortion and how it affects audio. Harmonics are multiples of the source, or a fundamental frequency, of a sound that makes the timbre more complex than just the fundamental. The harmonics of a fundamental at multiples of two are called even-order harmonics. Those that are at three, five, seven, nine, and onwards, are called the odd-order harmonics. Analog equipment can distort either odd or even harmonics, and that distortion will change the outgoing audio. Even numbered harmonic distortion “tends to sound musically
sympathetic, smooth, and bright” (Robjohns, 2010). Odd numbered harmonic distortion “tends to sound rough or harsh, gritty or edgy and is often associated with ‘richness’ and depth” (ibid). Analog equipment that has tubes will start to distort signals at a certain point when they are being overdriven and can give of their own character. Solid-state tape machines will generally have the odd numbered harmonic distortion, and it is part of the character that these machines provide. The amount of harmonic distortion from a tape machine will depend greatly on the way it was calibrated and the amount of signal being sent to tape. Overdriving tape is desirable to get tape saturation but too much will give off an unpleasing and overly distorted sound.

Tape saturation has to do with the record and playback heads, tape speed, record and playback EQs, and bias levels. These variables “introduce distortions of harmonic content, frequency and phase response irregularities, and they reduce dynamic range” (ibid). Calibrating a tape machine to be over-biased will improve the low- and mid-range distortions, but these improvements come at a price of the high frequency response. It is these differences that bring on "warmth" to the audio signal that flat-response, digital systems cannot replicate.

In the pre-digital days, tape would be mixed upon, bounced to, and have any number of overdubs with pass after pass printed onto the same reel of tape. The effects of wow, flutter, scrape flutter, and drift slowly begin to surface more and more by using tape over and over. Such repeated usage increasingly adds to the grunge and grit of tape. Sharp and loud, high frequency transients cannot be fully captured on tape. After passing over the tape multiple times, the high frequency
transients become even more harsh and the high frequency spectrum begins to slowly degrade.

Tape saturation also deals with the compression that the tape can give when overdriving a signal. When too much of the signal is being printed to tape, there might not be enough of the magnetic particles to write upon and then a small form of compression happens. It is this smooth compression, combined with a lack of dynamic range, and all the other previously mentioned factors that help tape give off analog warmth.

**Tape Versus Digital Comparisons**

In comparing audio between tape and digital systems in the following section, I will draw upon a source from engineer Adam Kagan. The samples that Adam Kagan provides are from a session at Ocean Way Studios in Hollywood, California. Kagan tracked acoustic and electric bass and electric guitar through one of the few Focusrite consoles in existence. After the console, Kagan split the signal to both the Pro Tools inputs and the tape machine inputs. Kagan used an Ampex MM1000 on two-inch, 3M 996 tape (Kagan, 2013). Each of the digital and tape samples were closely listened to and were analyzed by myself using BlueCat’s Frequency Analyzer 2 plugin. Each sample was sent out on their own left and right bus through a stereo auxiliary channel where I could analyze each of the samples frequencies by separating them left and right.

The first example is the acoustic bass tracks (Figure 1). These tracks were recorded with a Neumann U47 and a Neumann KM54 microphone and were mixed
together before being split. The bass is a great instrument to look at in terms of bass response and tape saturation. I soloed the first note of the bass line, which was an Eb, at 77.7 Hz. Under the analyzer the first note of Eb, the tape track is roughly +2 dB louder than the digital track. The tape track of the third harmonic at 234 Hz has a +1 dB of gain over the digital track as well as the fifth harmonic at 390 Hz. It is not until the seventh harmonic at 546 Hz that we see the digital having about a +1 dB of gain over the tape.

What is really noticeable is the amount of gain brought up on the tape track due to lack of dynamic range and the soft compression. From about 2 kHz and more noticeable after 5 kHz you can see an average gain of about 5 dB. Despite this gain in the high frequency, I think there is still something to be said for the small lack of high frequencies in the tape track. The high frequencies sound slightly loud but a little dull compared to the digital track.

The electric bass (Figure 2) was recorded through a custom made direct input box, or DI box, and then sent to both its digital and analog destinations. The digital track of the electric bass is the first time I have actually felt like digital sounds cold and fragile. Audio engineer’s descriptive words are vague, but there is something about the digital track that just does not sound warm. It might be the overall level or the grittiness of the tape, but the tape makes the electric bass sound more full. It feels like the low frequencies are meshed together while the digital track sounds crisp and clean.

When analyzed, the noise floor is really apparent in the tape track versus the digital track. The electric bass does not have much content past 2 kHz and the audio
starts to decrease at a large rate for the digital track from 5 kHz to 10 kHz. The tape track keeps a constant noise floor around 7 kHz between -98 and -102 dB. This noise floor is primarily the tape hiss but there is still a small amount of upward gain from the compressed dynamics that can be seen between 1.75 kHz to the 7 kHz range where the noise floor starts. Adam Kagan states at the end of his session that he ended up using the acoustic bass on tape for the entire album.

Electric guitar was recorded using a Neumann U47 and Sennheiser MD421 (Figure 3). The guitar microphones were combined into a mono signal and then sent to Pro Tools and to tape. The first guitar I analyzed was very fast and staccato and when I analyzed a section of the guitar, the left and right graph seemed to show relatively even frequency responses. When listening back, I got the same feeling I had from listening to the electric bass. There is grit to the guitar on tape that does not show up in the digital domain. Ideally, you would always want the cleanest recordings possible with the least amount of noise. Digital will win that argument every time but then there is usually a discussion: “Should it sound perfect and clean?” The electric guitar track is the a perfect example of slight harmonic distortion, a small amount of tape hiss, wow, and flutter that gives audio an analog feel. This feel is the result of tape machine nuances that is not quite achievable in the digital domain.

The second electric guitar used the same microphones and setup, but this guitar passage was a held chord that swelled (Figure 4). The tape hiss is apparent as the swell comes in on tape, but digitally, you can hear the swell form the very beginning. This is an instance where digital has a nice upper hand in giving more
dynamics due to its larger dynamic range and extremely low noise floor. Again, the frequency analysis of this guitar swell was extremely even and the noise floor can be seen around 7 kHz. Adam Kagan ended up using a variety of tape and digital guitar tracks based on mixing decisions. Adam liked the small rounding off of peaks through the soft compression but also really liked the clarity of the digital signals.

**Tape Versus Tape Emulation Comparisons**

For my own examples I will be looking at two different instances of tape versus tape emulation. The first example I have to look at is male vocals that were tracked to tape and brought into Pro Tools for examination. The second test I did was a stereo mixdown of a song looking at the effects of tape saturation.

The vocals were recorded through a Wunder CM7 microphone, a Neve 5012 preamp, were split at the output of the preamps, and were then sent to Pro Tools and tape. Afterwards, the digital version was than sent through the UAD ATR-102 plugin with my Ampex AG-440 custom preset. This custom preset was made by examining the amount of noise from my AG-440 and matching it to the ATR-102. I then adjusted a 50/50 ratio of wow and flutter to simulate a generous but not overly obvious amount of the two. I then set the same tape formula, tape head width, and tape speed to match my machine as well.

When comparing the tape emulation and tape tracks they are strikingly similar. When analyzed the low end and low midrange of the tape track have a slight boost of 1-2 dB compared to the tape emulation. The drop off in response for both the emulation and analog track start at about the time frequency range of around 9
kHz. This preset is not perfect and because of the ease of use, a small adjustment to
the low EQ shelf can be raised, and then the plugin can react more similarly to the
tape track. There is still something to be said in reference to the tape hiss. The
difference between the actual tape hiss from the Ampex machine and the tape hiss
from the Ampex emulation is small but noticeable. This hiss on the actual machine
easily influences high frequency information especially when the high frequencies
reach the noise floor. I would use the tape for that certain sound you get from the
nuances of the actual tape machine but in terms of frequency it is quite similar.

The second test is sending a stereo mix of “Stardust,” by Lillie Lemon,
through the tape machine and tape emulation at three different levels to see the
amount of tape saturation achievable. This test proved challenging when trying to
“overdo it” and get a large amount of compression on the plugin compared to the
large amount of compression on the actual tape machine.

The first test is simply sending the mix through the tape machine and the
tape emulation where the loudest peak in the song reaches +0 dB (Figure 5). The hi
hat is heavily used in this song and you can clearly hear a reduction of the dynamics
in both examples but there is more saturation and loss of dynamics occurring in the
tape example. The high frequencies are slightly attenuated in the tape machine track
and another plus side to the emulation plugin is by two clicks of the mouse I can
attenuate the high frequencies of the emulation to match the tape. This comparison
was hard to choose because they both sounded great but the tape still had the edge
on the tape emulation in terms of sound. When it comes to ease of use, the
emulation would easily win. However, engineers in possession of a tape machine
who want the real effects of tape saturation and the nuances tape creates will
certainly benefit from the real thing.

The second test was done by making the loudest peak in the mix slightly pass
the +3dB marker on the VU meter for the machine and the emulation (Figure 6). The
tape emulation had an incredible sound and rounded out the edges of the mix quite
well. The tape track gave a greater loss of dynamics and brought the whole song up
a little more. The tape track seemed to have a fuller low frequency response in the
bass, kick drum, and tom hits. The loss of dynamics in the tape is not beneficial but
having a glue-like effect to make the mix sound more whole is a nice touch. Out of
the two saturated tracks, I would choose the tape emulation.

Last but not least is what I call “overdoing it.” For both these examples I
chose to really drive the emulation and the tape machine and max out the VU meters
to the point of near “brick wall” processing (Figure 7). The tape machine examples
are the obvious winner in this comparison. By trying to replicate the amount of tape
saturation in the tape emulation, digital distortion starts to occur before a brick wall
effect even takes place. The tape track is slammed and has almost completely lost its
dynamics, but it still sounds good. It is not a desirable choice for a final mix, but for
limiting a bass guitar or other wildly dynamic instrument it is perfect. The tape
emulation ended up sound slightly louder because of peaks not truly being overly
saturated by tape but the digital distortion is wildly apparent in the snare and kick
hits. On the other hand, the tape during the same section sounds very musical and
no sort of clipping occurs. If overly saturating a track were desirable, then tape
would be the right choice.
Conclusion

By hearing the origins and history of tape, it is clear that it has had quite a journey from magnetic wire, to World War II, to studio use, to a new age of digital recording. The tape machine helped make thousands of albums between the 50s, 60s, 70s, and 80s. Though tape might have seen its day, it will still continue to be a desired sound for bands, and engineers in the tracking, mixing, and mastering fields. For some studios the use of an actual tape machine might seem too expensive and tedious but the subtleties of physical tape are too hard and too minute to replicate still. There is something to be said about tape emulation and the ease of use, low cost, and extreme portability that make them viable options. With the amount of inexpensive emulations for sale and the high cost of a physical tape machine, engineers will continue to make whichever choice makes sense. If a studio has the space, money, time and resources to own a physical tape machine, it is the advice of this author to buy one, make comparisons and really decide which is more beneficial to your work.
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Figure 4
Top-Digital, Bottom-Tape

Figure 5
Purple - Tape, Blue - Tape Emulation

Figure 6
Red - Tape Emulation, Purple - Tape
Figure 7

Green – Tape Emulation, Purple - Tape