Digital Data on Cassette Recorders

(The Demise of an Overworked Carry-Corder)

Harold A Mauch
Pronetics Corp
PO Box 28582
Dallas TX 75228

Nearly everyone has a portable cassette recorder. If you don't have one, chances are your kid does ("Hey, Mom, Dad stole my tape recorder!"). These recorders range from the under $20 "bare bones" variety to multi centibuck units with nearly every feature imaginable. Fortunately it should be possible to use nearly *any* cassette recorder available if it is clean and in good working condition. Pawnshops and similar outlets are good sources of used cassette recorders. Used recorders are often quite dirty and may need repair. Take along a couple of test cassettes when you go shopping and check out the units' operation before buying.

Watch out for bent capstans and broken cassette holders since these often are not repairable and indicate excessive abuse.

Some dictating and "pocket secretary" cassette recorders do not use a capstan drive system. While these recorders are usable, it may not be possible to exchange programs recorded on these machines with a friend. Stick with the capstan driven recorders.

While nearly any cassette recorder is usable for storage of digital information, some units have features which improve performance or convenience.

Tops on the convenience list is a *digital tape counter*. Next to destroying a valuable recording, nothing is more frustrating than not being able to find a desired program on a cassette with several programs. The tape counter solves this problem. Merely reset the counter with the cassette fully rewound and write the counter reading of the start of each program on the cassette label. Some of the newer cassette recorders also have cue and review capability. While occassionally useful, these features are not really necessary.

A recorder with an AC *bias and erase oscillator* will produce the most reliable performance and highest quality recordings. Unfortunately most of the under $100 cassette recorders now available erase and bias the tape with DC.

DC erased and biased recordings have more low frequency noise and residuals and poorer high frequency response than AC bias recordings. Cassette recorders designed for music recording usually have circuitry to erase and bias the tape with a 50 to 100 kHz signal. These same recorders usually have drive motors which are speed controlled by the power line frequency. The result is more precisely driven and recorded tape. Since

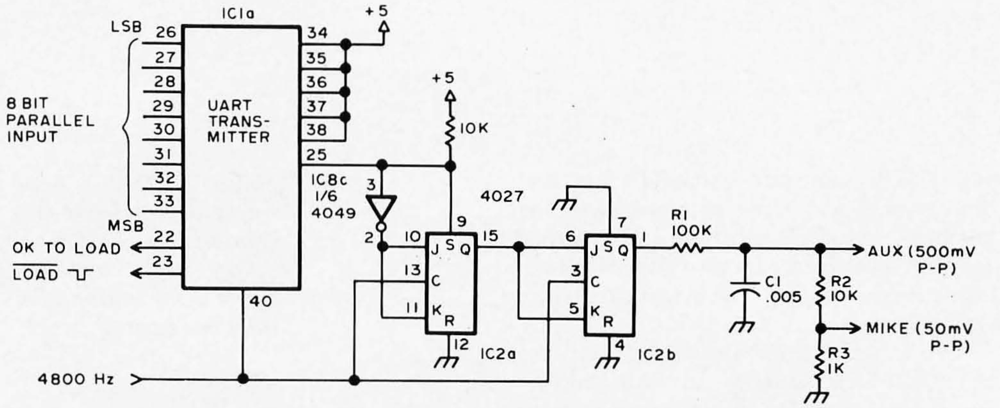

Figure 1: Cassette digital modulator. This circuit converts 8 bit parallel data from a computer into a series of 2400 Hz and 1200 Hz tones using a UART. Filtering provided by C1 and R1 is used to turn the square wave outputs of IC2b into a closer approximation of a sine wave (see figure 2).

these are normally stereo recorders, be sure to bulk erase the cassette first to remove the residual signals between the stereo tracks. If you apply the signal to be recorded to both channels, the resulting recording will be usable on any of the portable cassette players.

The cassette tape unit you select must have an auxiliary (AUX) or microphone input and a line or earplug output. This is the only reasonable way to connect the cassette tape unit to the necessary modulator/demodulator circuitry. Acoustic coupling through the microphone and speaker is totally unsatisfactory.

Pause controls are nice but not necessary.

Use the cassette tape unit available to you, but remember you only get what you pay for and these days even that costs more.

Choice of Cassette and Tape

The choice of cassette cartridge and tape has more effect on performance than *all* other factors combined. This is no place to save a penny or even a buck. Get the very best tape you can buy. Do not even consider anything less than the super tapes. If your recorder can record the chromium dioxide tapes, use them. Anything less than the best will result in much frustration. Avoid using the C90 and C120 cassettes. The tape is too thin and fragile. C60 and shorter tapes are much more rugged.

If a cassette is not in use it should be stored in its container in a dust free location. Keep the cassette tape unit spotlessly clean and do not smoke in the room in which the cassette equipment is used or stored.

It is impossible to adequately stress the importance of buying the very best quality tape and then keeping it and the tape unit clean. Tape quality and cleanliness is much more important in digital applications than in the more conventional speech or music applications.

Getting the Digital Information onto the Cassette

There are many ways to record digital information on audio cassette tapes. Many of these techniques work quite well as long as the data is played back on the same machine as was used to make the initial recording. Rather than debate the merits and deficiencies of the various techniques, the author has chosen to support the proposal suggested for evaluation by the BYTE sponsored symposium on audio digital cassette recording. I feel the proposal adequately accommodates the limitations imposed by conventionally available audio cassette tape units.

Digital information from your computer is generally available as 8 bits parallel from an IO port or data bus. The recording on tape must be serial with start and stop delimiting bits. The transmitter portion of the UART is ideal for converting the parallel data to this serial format. Figure 1 is a circuit implementing such a converter or modulator.

The serial output of the UART is said to be NRZ (non return to zero). It means that a logic one bit is a high level and a logic zero bit is a low level. A logic one causes the modulator to generate a 2400 hertz output signal and a logic zero generates a 1200 hertz signal. Normal output from the modulator is a string of square waves. The sharp edges of the square wave signal do not usually record well on recorders with DC recording bias. The designers of such recorders "roll off" the amplifier low frequency response and boost high frequency response in an attempt to diminish the drawbacks of DC biased recording. This causes a square wave to be abnormally "peaked" on the rising and falling edges and the flat portions to be "tilted." Refer to figure 2.

Such signals are more likely to cause errors during playback. Ideally the modu-

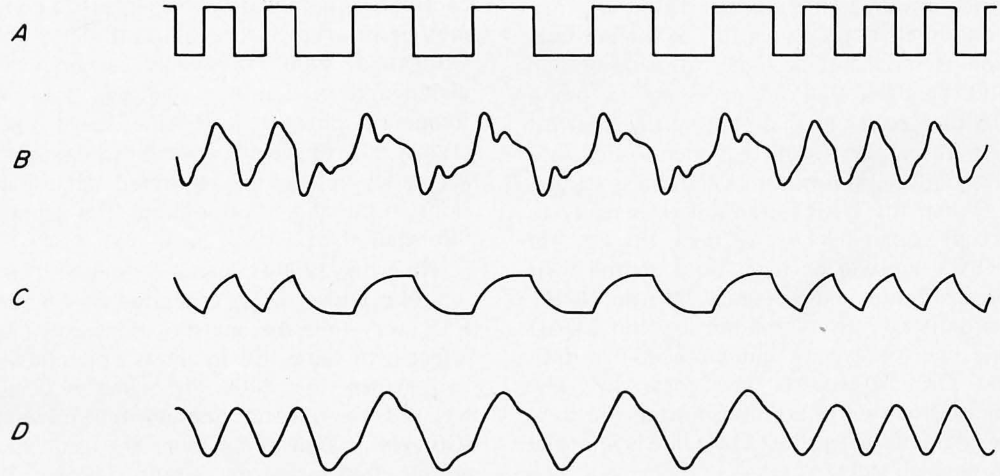

Figure 2: If a square wave signal such as waveform A is recorded on a low cost cassette recorder, the playback response may look like waveform B, which is very difficult to demodulate. If the square wave is filtered with a low pass filter before recording (waveform C), the playback response will look like waveform D, which is a usable signal.

lating signals should be sine waves but generating and switching sine wave signals digitally is somewhat complicated. "Rounding the square wave corners" with a low pass filter (R_1 and C_1 in figure 1) is not totally effective but does provide a usable waveform.

The AUX output is a 500 mV peak to peak signal. This signal level will overdrive a microphone input and should only be connected to the recorder auxiliary input (50 kOhm or greater input impedance). The MIKE output is 50 mV peak to peak and will drive most cassette microphone inputs.

The 4800 Hz signal should be as precise as possible and capable of driving 2 TTL loads. Ideally it should be obtained from a crystal oscillator and divider string or a phase locked loop (PLL) locked to the power line frequency. If such stable sources are not available the circuit shown in figure 3 is satisfactory but it must be accurately adjusted with a frequency counter.

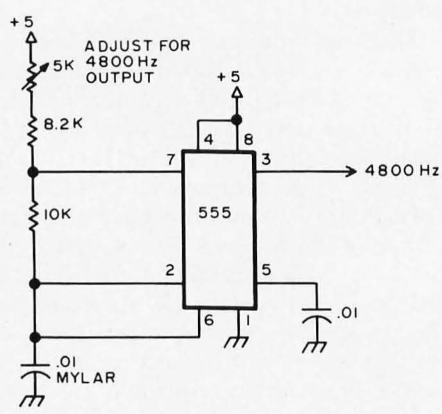

Figure 3: Circuit of a 4800 Hz oscillator. This oscillator, using the 555 precision timer circuit, can be used if a crystal controlled or line frequency derived timing source is not available.

If the available digital information to be recorded is already in serial form with the necessary start and stop bits (2 stop bits are required) and is being sent at 300 baud, the UART transmitter is not necessary. However, the 4800 Hz clocking signal should be synchronous with the serial digital information (16 clock pulses per bit). If the information is serial but at some rate slower than 300 baud, it will be necessary to use a UART receiver to first convert the information to parallel form. It is then loaded into the UART transmitter as described earlier.

When the UART transmitter is ready to accept a parallel byte of data, the OK TO LOAD line will be high. Data on the eight parallel input lines is loaded into the UART transmitter buffers by pulsing the LOAD line low for at least 1 microsecond or until the OK TO LOAD line goes low. The transmitter will start transmitting the byte or character when the LOAD line is returned to the high state.

If the UART is not transmitting any data, its serial output line is high, causing the modulator to generate the 2400 Hz signal.

Playback of the Recorded Data

Since the signal recorded on tape is basically a standard FSK (frequency shift keyed) signal, it is possible to recover the digital signal with a phase locked loop (PLL) or FM discriminator. In fact, users of the Suding cassette system (wide shift audio FSK) should be able to recover the NRZ data signal by readjusting their demodulators. However, data recovery by these means is not as precise nor as insensitive to tape speed variations as digital recovery techniques which extract speed insensitive timing pulses from the recorded signal and use these pulses to retime the NRZ data.

Figure 4 is a complete schematic of the playback recovery circuit or demodulator.

The cassette earplug output signal is conditioned by the operational amplifier Schmidt trigger IC3. IC4 is a retriggerable one shot with a period of 555 microseconds. As long as the 2400 Hz signal is being received, the one shot is constantly retriggered and does not time out. This causes flip flop IC5a to remain at the high state interpreting the data as a logic one. When the 1200 Hz signal is received, its period is long enough to allow the one shot to time out. Flip flop IC5a is immediately reset. It stays at the low state as long as the 1200 Hz signal is being received, because the one shot is timed out whenever the next triggering edge occurs. When the 2400 Hz signal returns, the one shot output stays high, thereby permitting the flip flop IC5a output to switch to its high state. The output of flip flop IC5a is the recovered NRZ serial data.

Under ideal circumstances, the recovered data would be sufficiently stable to drive a 300 baud teleprinter or TV typewriter directly. However, if the tape speed varies in excess of approximately ±6 percent (a common occurrence), errors will result. Since the 1200 and 2400 Hz signals carrying the digital information on tape will vary in frequency directly with tape speed variations, it is possible to use these signals to accurately retime the recovered data. Flip flops IC6a and IC6b extract this timing information.

When the 1200 Hz signal is received, IC6a is preset with a pulse generated by C8 and R15 every time the one shot times out. The effect is to cause IC6 to act as a division by two. When the 2400 Hz signal is being received, the one shot does not time out and IC6 acts as a divide by four. The result is a double clock rate at the output of IC6b.

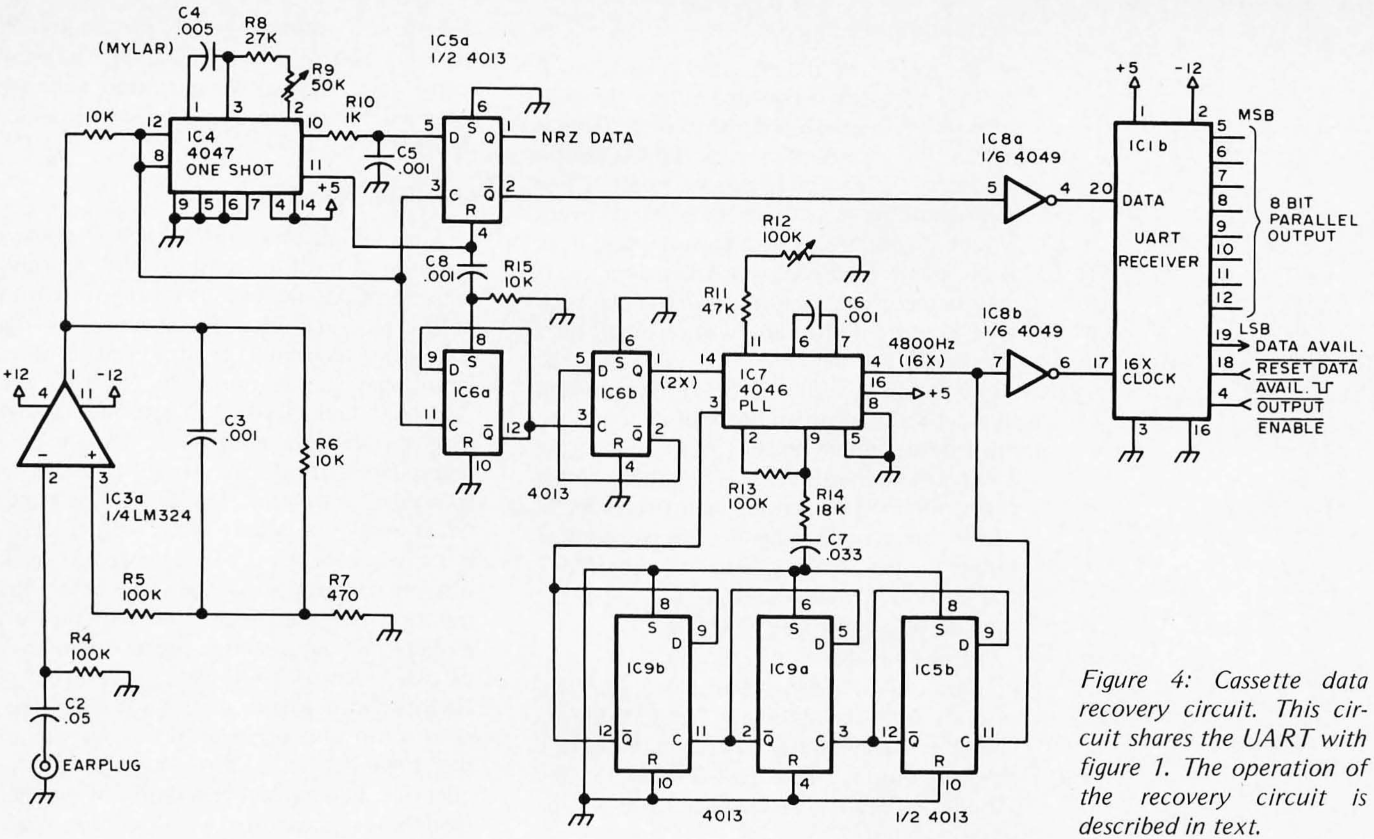

Figure 4: Cassette data recovery circuit. This circuit shares the UART with figure 1. The operation of the recovery circuit is described in text.

Instead of clocking the data into a shift register, it may be more desirable to use the receiver portion of a UART, since the UART receiver has built in circuitry to identify the beginning and end of each byte or character automatically. Furthermore, the UART parallel data outputs are 3-state, which permits convenient direct connection to most IO ports or data buses. (For a more detailed discussion of the UART, you may wish to read "Serial Interface" by Don Lancaster in BYTE, September 1975).

However, the UART requires a clock at 16 times the data rate. This problem is solved by phase locking an oscillator at 4800 Hz to 600 Hz (2X) ouput of IC6b. The phase locked loop (PLL) oscillator is adjusted for 4800 Hz in the absence of any input signal. IC5b and IC9 divide the PLL oscillator output by eight and drive one of the PLL phase detector inputs. The other phase detector input is driven by the 2400 Hz clock output of IC6b.

When the UART receiver recognizes that it has received a complete character, it raises its DATA AVAILABLE output line to logic one (high level). Since the UART outputs are 3-state, it is necessary to drive the RECEIVED DATA ENABLE input to logic zero (low level) to read the parallel output data. After the parallel data has been read, it is necessary to pulse the RESET DATA AVAILABLE line to prepare the UART to output the next byte or character. The pulse must remain at logic zero for a minimum of one microsecond or until DATA AVAILABLE drops to logic zero.

Circuit Adjustments

As already stated, the 4800 Hz signal used to drive the UART transmitter and modulate the tape recorder should be obtained from a very stable and accurate source for best results. No other adjustments are necessary on the recorder modulation circuits.

The data recovery one shot and the phase locked loop oscillator in the playback data recovery circuits must be accurately adjusted for best results. The most critical adjustment is the period of the data recovery one shot. An easy way to adjust the period is to connect a well calibrated audio oscillator to the earplug input of the data recovery circuit and a high impedance voltmeter to the NRZ data output (IC5a pin 1). Set the audio oscillator for 1800 Hz and the output level for 1.5 to 3.5 volts RMS. Adjust R9 until the voltmeter reading just changes (use the 5 to 15 volt scales). Get the adjustment as close to the point of change as possible.

The PLL oscillator is adjusted for 4800 Hz (R12) with no connection to the earplug input. If a frequency counter is not available, compare the PLL oscillator output (IC7 pin 4) to the 4800 Hz signal used to drive the UART transmitter.

Operating Procedure

The playback data recovery circuit will operate best with an earplug output signal of between 4 to 10 volts peak to peak. This is within the range of most portable cassette recorders. It may be necessary to put a low gain amplifier ahead of the data recovery circuit if you are using a cassette tape deck not capable of driving a speaker directly. It may be necessary to turn down the playback tone control if the tape was recorded on a DC biased recorder.

To comply with the BYTE Symposium Standard, the recorded block of data on tape must have a minimum of five seconds of the 2400 Hz tone before data is recorded. This is easily obtained by permitting the recorder to run in the record mode for five seconds or longer before sending data to the UART transmitter. When the UART is idle the modulator is generating 2400 Hz.

During playback it is recommended that you wait until the playback is one or two seconds into the 2400 Hz "leader" before allowing the computer to accept the UART receiver output. This is to avoid reading "trash" caused by turning the cassette tape unit on and off.

It is possible to turn the cassette tape unit on and off with a relay under computer program control using the cassette tape unit remote control input. However, the cassette will record and playback "trash" during the startup and stop intervals which may take as long as 3 to 5 seconds. The 2400 Hz signal recorded on tape before each block of data gives the computer a "trash free" interval in which to prepare itself for the data to follow.

Circuit Design Considerations

It will be some time before enough information has been learned about the use of audio cassette recorders for storage of digital information to permit truly optimum designs of the necessary modulator/demodulator circuits. Therefore the author would like to present his design considerations to provide other experimenters and designers a starting point for additional experimentation and optimization. The comments are somewhat technical and are intended for the advanced experimenter or designer.

Modulator Waveform

The nonlinearity and skewed frequency response of most low cost cassette recorders impose serious limitations on the waveform of the recorded signal. In severe cases, the waveform recovered from a square wave input may be so seriously "tilted" and "peaked" and filled with overshoots that data recovery is impossible. Obviously a better modulating signal would be a sine or triangular waveform. On the other hand, "doctoring" the square wave with filters is attractive from an economic viewpoint. Such filtering can only be carried so far before the resulting differential amplitude of the two modulating frequencies produces "pumping" of the recorder automatic level control circuits and begins to diminish the signal-to-noise ratio and signal drop out margins of the higher of the two modulating frequencies. Economical generation of a better modulating waveform will go a long way toward improving data recovery reliability with simple recorders.

Modulator Signal Level

The signal level applied to the recorder appears to be relatively uncritical. However, I feel the level should be standardized; but I am not prepared to recommend a preferred level at the present time.

Demodulator Signal Conditioning

Many experimenters have used simple zero crossing comparators to condition the playback signal. While these circuits have tremendous immunity to signal drop out, they are quite sensitive to "drop in noise" and tend to "chatter" at low signal levels or in the absence of an input signal. I prefer a circuit with sufficient hysteresis to provide some margin against the drop in noise and residuals and to prevent chatter. The ideal

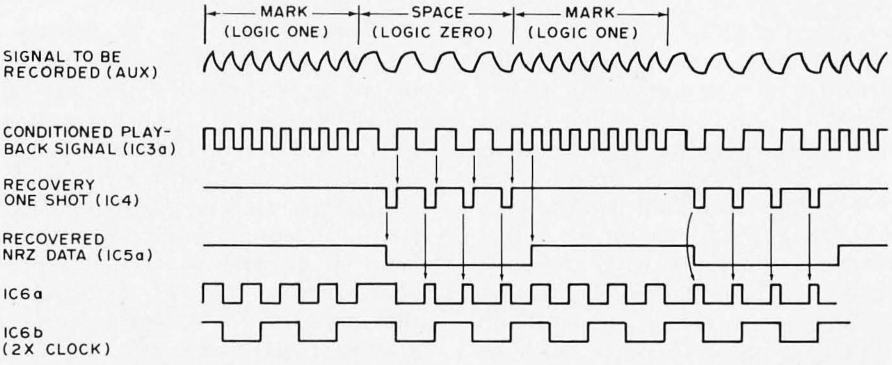

Figure 5: Cassette modulator demodulator wave forms. The signal presented to the tape recorder is a filtered square wave, shown at the top. The timing of data recovery is shown relative to the conditioned playback signal in the remaining five traces.

trip points for such a circuit is probably in the range of 20 to 30 percent of peak signal. The trip points of the circuit described in this article are approximately ±0.5 volt. Best performance will then be obtained from 3.5 to 5.0 volt peak to peak input signals.

Demodulator One Shot

If the one shot is properly adjusted, the data is recoverable with tape speed variation in excess of ±30 percent from nominal speed. I have found the speed distribution of the portable cassette tape units to be skewed roughly 5 percent negative. If a tape is played on the same unit as was used to make the recording the problem is negligible. If, however, the tape was prepared on precision tape recording equipment (such as may be used for mass production of cassettes for widespread distribution), then played on a consumer quality tape player, the tolerance of the recovery circuit to a decrease in tape speed will be diminished. This may provide some argument for increasing the period of the one shot 5 percent.

A characteristic of the data recovery circuit used is that it causes an approximately 6 percent marking bias in the recovered waveform. This is not too important if the data is recovered by a shift register or clocked into a UART receiver. A purist approach would delay the space to mark transition 6 percent of the nominal bit cell duration.

Some experimenters filter the recovered data waveform to provide an additional immunity to error. I have not found it to be necessary and have found it creates more problems than it solves.

Demodulator Phase Locked Oscillator

The PLO is only necessary because the UART requires a clock at 16 times the data rate. The phase detector output is filtered with a lag-lead network. The filter was designed to permit capture of signals ±15 percent from nominal speed with a 0.707 damping factor. Consequently, the oscillator will remain locked during ±15 percent step changes of the input signal frequency. Once locked, the oscillator will track the input signal over a ±70 percent range. The sum frequency component of the phase detector output does modulate the oscillator slightly but was not considered to be a problem. This modulation can be diminished by increasing the loop filtering; however, this reduces the capture range which is undesirable.

Conclusion

The use of hardware to modulate and demodulate the cassette tape simplifies the programming problems associated with using the cassette for program loading and storage. In some circumstances it may be possible to connect the cassette hardware interface directly to your panel switches and display drivers and "let it rip." Other systems may require peripheral interface adapters or other similar circuitry to get the data onto and off the computer data bus.

The cassette interface described in this article is manufactured by Pronetics Corporation. It is available fully assembled and tested on a 4.5 x 6.5 inch circuit card with connections through a standard dual 22 pin gold plated card edge connector. Price, availability, and other information may be obtained by writing: Pronetics Corporation, PO Box 28582, Dallas TX 75228. ■