Before there was Martin, before there was Scottie, before there were VIS codes, soundcards, JVFAX, and Hamcomm interfaces, Slow-Scan TV images swept across P7 phosphored CRTs in 8 seconds (or less), and it was a truly fascinating phenomenon.
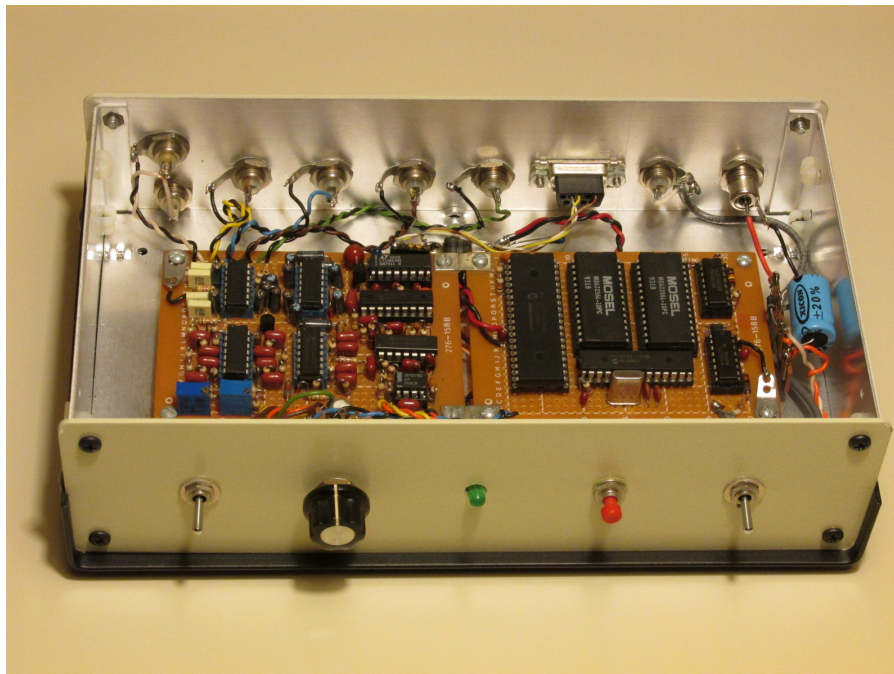
Over time, storage tubes, charge coupled devices, shift registers, random access memories, and countless TTL chips made scan conversion a reality, and it was nothing short of amazing. There was just one SSTV standard, and its compatibility was universally shared.

Evolution in scan converter technology paved the way for the development of many color SSTV formats and protocols. The once universal monochrome format was eventually abandoned and given up for dead, well before the popular scan converters of the day could actually render the full resolution of an 8 second transmission.

Today, slow-scan television signals are handled almost exclusively in the software domain, and SSTV is now considered to be just one of many "digital modes" of communication. Unfortunately, when specialized communication modes such as SSTV become just another software application, the PC becomes the center of attention, and the mode's relevance in our Internet and cellphone dominated world gets lost in the process.

One way of reversing this trend and bringing the fascination and the mystique back to Amateur Radio is to refocus our attention on the electronics that makes our unique modes of communication possible. The TriplePIC SSTV Video Scan Converter was created as a means of doing just that. It was born out of a desire to revisit a time when an 8-second image transmission was considered "long", and to thoroughly assess the capabilities of the original monochrome SSTV standard using signal and image processing techniques superior to any popular SSTV monitor or scan converter available in the past. Not only has this feat been accomplished, but the performance of the TriplePIC has also been shown to surpass that of modern PC-based SSTV software as well.

Gaining an appreciation for the design and operation of the TriplePIC scan converter requires a review of the 8-second SSTV video format, as well as a look back to some SSTV hardware design concepts from the past that helped mold the TriplePIC's design.

The KD2BD TriplePIC SSTV Video Scan Converter

SSTV Signal Characteristics

Since the 1960s, slow-scan television has employed subcarrier FM as a means of conveying SSTV's low-frequency baseband video information over AC-coupled communications-grade audio circuits. Modulation characteristics are such that white is transmitted at a frequency of 2300 Hz, black is transmitted at 1500 Hz, and sync pulses are transmitted at 1200 Hz. Prior to the advent of line sequential color in the early 1980s, SSTV video employed 120 scanning lines transmitted at 15 lines per second, with an 8 second frame rate, presented in a 1:1 aspect ratio.

Slow-scan's horizontal and vertical sweep rates were originally referenced to the frequency of the local power grid to minimize the effect any stray magnetic fields from power transformers might have on the CRTs in SSTV monitors. Areas of the world served by 60 Hz power employed 15 Hz (60/4) horizontal and 8 second (120/15) vertical sweep rates, whereas 50 Hz areas used 16.666 Hz (50/3) and 7.2 (120/16.666) second sweep rates.

The construction and placement of sync pulses within the video waveform was such that the start of each video frame was initiated by a 30 ms wide vertical sync pulse, while the end of every video line, except the last in the current frame, was identified by a 5 ms wide horizontal sync pulse.

When it became popular to generate SSTV signals using digital logic circuits, the number of horizontal scanning lines was increased from 120 to 128, which added a little over one half second to the vertical frame rate. However, this minor change was completely compatible with all the earlier SSTV equipment in use at the time.

SSTV Video Demodulation Methods

Having a stable set of SSTV transmission standards in global use for several decades led to the development of a wide variety of SSTV monitors, flying spot scanners, scan converters, vidicon, and Plumbicon-based cameras, years before their appearance on the commercial market. Out of these many designs came an assortment of proven methods for successfully demodulating and rendering slow-scan television images.

Copthorne MacDonald, the Father of SSTV, originally used an LC network that demodulated SSTV video by way of slope detection. Sync pulse detection was handled by a second LC network that served as a 1200 Hz bandpass filter. MacDonald's simple but effective method for SSTV demodulation was adopted by W7ABW and W7FEN in their popular "Slow-Scan TV Viewing Adapter for Oscilloscopes", and by W9LUO in his Mark I and Mark II P7 monitor designs in later years.

Robot Research, Inc. took some variations to this approach in the design of their model 70 SSTV monitor. Robot engineers employed a double tuned Travis FM discriminator that demodulated SSTV signals with linearity better than what could be obtained using a slope detector. Like the slope detector, the Travis discriminator provided a measure of selectivity that helped reject interference and noise outside the occupied bandwidth of the SSTV signal. Travis discriminators were also employed by the SEEC model HCV-2A SSTV monitor, the G3WCY Digital Scan Converter, and the legendary Robot model 400 scan converter in later years.

While the slope detector and Travis discriminator operated in the frequency domain, zero crossing detectors operating in the time domain started to grow in popularity during the 1970s due to their simple designs and use of low cost components. Time domain demodulators produced a DC voltage (or equivalent digital representation) related to the instantaneous frequency of the SSTV signal. This approach was employed in SSTV monitors and scan converters designed by Dr. Robert Suding, W0LMD, Dr. George Steber, WB9LVI, the Venus Scientific model SS2, and the SBE model SB-1 SSTV monitors. Zero crossing detectors were also employedin the Pasokon PC-based SSTV system and the very popular Hamcomm SSTV hardware interface.

Since the waveform of any signal, desired or otherwise, is equally capable of triggering a zero crossing detector, the performance of time domain-based demodulators was easily degraded by noise and interference. Furthermore, unless the half-cycle period the waveform was measured, a lot of fine picture detail was lost. Not every time domain implementation provided half-cycle resolution, and not every implementation yielded a high degree of linearity.

SSTV Sync Detection Methods

Many variations in sync detection were employed in SSTV hardware over the years as well. While the earliest SSTV monitors (and later Venus model SS2) utilized dedicated bandpass filters to detect and separate the 1200 Hz sync pulses from the composite video signal, many SSTV hardware designs that followed did not. The WB9LVI, Robot, SEEC, and SBE designs demodulated the composite video signal in its entirety, and stripped sync pulses from the "blacker than black" portion of the demodulated video waveform. While this approach simplified sync detection circuitry, made SSTV reception less critical of exact receiver tuning, and more tolerant of frequency drift, it did so at the expense of noise immunity and sync stability.

Poor sync performance also carried over into many of the early SSTV scan converters, while economics forced compromises in other areas of circuit design as well. For example, WB9LVI's Slow to Fast Scan Converter and the extremely popular Robot model 400 Scan Converter that followed undersampled SSTV into just 128 pixels per line, each having one of only 16 shades of grey. When performing slow-scan to fast-scan conversion, the Robot 400 displayed each SSTV line twice in succession to fill the 256 lines of the non-interlaced FSTV video frame it produced. However, WB9LVI's scan converter averaged the greyscale levels of adjacent SSTV lines and pixels in an effort to enhance the resolution of the upconverted 256-line fast-scan TV image.

The Bottom Line

The numerous design trade-offs and performance deficiencies inherent in many of the popular SSTV scan converters, video monitors, and PC interfaces of the past created a false impression that the 8-second SSTV standard was less capable than it really was. Even some of the PC-based SSTV applications available today do a poor job of rendering the 8-second image format, if they support it at all, further reinforcing that false impression. The outstanding performance demonstrated by the TriplePIC SSTV Scan Converter suggests this popular view is overly pessimistic.

The TriplePIC Design

The TriplePIC handles scan conversion in a two-step process. Signal demodulation, A/D conversion, and serial data encoding functions are handled in the circuitry illustrated in Figure 1. Image storage and D/A conversion at the Fast-Scan TV rate take place in the circuitry illustrated in Figure 2.

A high-speed serial data link connects the SSTV demodulator with the image storage and FSTV display sections of the scan converter. An RS-232 port permits access to this data link by external devices, making display of SSTV video possible on PCs, Raspberry PIs, or even a classic P7 CRT.

The Front End

The TriplePIC employs high-speed, rail-to-rail operational amplifiers throughout all of its analog circuitry. A Texas Instruments TLE2426 "rail splitter" provides a precision virtual ground at +Vcc/2 (2.5 volts) for every operational amplifier, making the entire unit capable of operating from just a single +5 volt DC power source.

SSTV signal processing begins in Figure 3, where one section of an LMC6484 operational amplifier is used to amplify and limit the amplitude of the incoming SSTV to a 5 volt peak-to-peak square wave. Independent video and sync demodulators follow the limiter.

Video Demodulation

Video demodulation is performed by a Travis discriminator consisting of a pair of active bandpass filters, precision full-wave rectifiers, a differential summing amplifier, and an 8-pole 1300 Hz Butterworth low-pass filter.

U1A and U1B form the discriminator's bandpass filters, the bandwidth and center frequencies of which capture the full spectrum occupied by the video portion of the SSTV signal. The output of each bandpass filter is full-wave rectified and differentially summed in U1C. Best performance is realized when the resistances of R8, R9, R10, and R16 are closely matched to within a few percent of one another.

Subcarrier ripple present at the output of the summing amplifier is removed by the low-pass filter formed by op-amps U3A, U3B, U3C, U3D, and their associated passive components illustrated in Figure 4. The output of U3D is a DC voltage that is linearly proportional to the frequency of the incoming SSTV video signal. Additional gain provided by U5D raises the peak-to-peak video level up to the power supply rails so that SSTV black produces an output voltage of zero volts while white produces five.

The frequency response of the entire video demodulator is flat from DC to at least 128 vertical lines of resolution.

Sync Detection

Sync pulses are extracted from the composite SSTV signal by the circuitry illustrated in Figure 5. A fourth-order bandpass filter designed around operational amplifiers U4D and U4C separates the 1200 Hz sync pulses from the higher frequency video. This bandpass filter has a 3 dB bandwidth of 140 Hz, which is theoretically optimum for the detection of 5 ms long horizontal sync pulses. Its response is down 16 dB at 1500 Hz, the lowest SSTV video carrier frequency.

Subsequent full-wave rectification provided U4B and U4A, and the low-pass filtering that follows in U5A and U5D, produce raised cosine shaped DC pulses for every vertical and horizontal sync pulse received. The transient response of each low-pass filter have been optimized to exactly match those of the 5 ms horizontal and 30 ms vertical sync pulse lengths.

First PIC

Demodulated SSTV video and sync are processed by U7, a Microchip PIC16F88 microcontroller illustrated in Figure 6. Video is applied to the microcontroller's A/D converter, while detected vertical and horizontal sync pulses are applied to two of the microcontroller's voltage comparators. The threshold voltage for the comparators is set within the PIC16F88's firmware to a level approximately equal to one half the peak amplitude of the detected sync pulses.

256 A/D samples are taken during the active portion of each SSTV video line. U6, an LM555 oscillator, generates interrupts within the PIC16F88 that initiate each A/D conversion. The LM555 oscillates at approximately 4151 Hz for video sources synced to a 60 Hz power grid, and 4654 Hz for 50 Hz referenced SSTV. The specific rate of operation is selected by switch SW3 and associated trimpots R62 and R63. To ensure that the start of the A/D sampling process is properly aligned with the start of each video line, the LM555 is reset through transistor Q1 on the trailing edge of every horizontal sync pulse received.

Propagation delay through the 1200 Hz bandpass filter causes the detection of horizontal sync pulses to be delayed approximately 5 ms in time. Several more milliseconds of delay are imposed by the low-pass filter that follows the full-wave rectifier.

In order to properly re-align the video information with that of the delayed sync, incoming video is propagated through a 30 byte FIFO buffer after it has been digitized by the PIC16F88. The buffer serves as a digital delay line, and its output is merged with the detected sync and sent via a 115.2 kpbs asynchronous serial data link to U11, the second PIC in the scan converter. This serial data is converted to RS-232 voltage levels by U8, a Linear Technologies LT1181A RS-232 driver, so that it can be made available for use by peripheral devices.

Serial data is encoded such that black is transmitted as 0x01, and white is transmitted as 0xFF. A string of 10 0x00 bytes or more in a row (nominally 20) represents horizontal sync, while 100 or more 0x00 bytes in a row (nominally 125) represents vertical sync.

Second PIC

Serial data from the PIC16F88 is received by U11, a PIC16F77 microcontroller shown in Figure 7. This second PIC keeps track of the SSTV video line and pixel address being processed, and writes each pixel to the appropriate address of a 64 kilobyte array of static RAM (U16, U17) during the FSTV horizontal blanking intervals. It also averages adjacent lines of video, effectively doubling the number of lines present in the SSTV image to provide resolution enhancement and format compatibility with the NTSC fast-scan television standard.

Third PIC

Scan converter output in the form of FSTV video is made possible by U12, a PIC16F76 microcontroller and its associated components illustrated in Figure 7. The PIC16F76 causes SSTV pixel data stored in video RAM to be read through U13, a Texas Instruments TLC7524 D/A converter. With the aid of U15A, a CD4053B analog multiplexer, all corresponding FSTV sync pulses and blanking intervals are generated to produce a composite, non-interlaced, 256x256 pixel NTSC fast-scan video signal.

Since SSTV images have a 1:1 aspect ratio, they need to be presented in a pillarbox format when they are upconverted to FSTV's 4:3 aspect ratio. This feat is accomplished by filling the center 75% of each fast-scan active line with SSTV pixels, and extending the width of the horizontal blanking intervals to fill the left and right sides of the display with a black border.

Operating the PIC16F76 at 24 MHz gets us close to achieving these parameters while employing a commonly available crystal. The output of the third PIC's 24 MHz oscillator is daisy-chained through the second and first PICs. While all three microcontrollers are rated by the manufacturer to operate at a maximum clock frequency of 20 MHz, they operate flawlessly at 24 MHz.

Performance

Figure 9 illustrates the image resolution obtained with the TriplePIC scan converter compared with those from 1970s magazine ads for the Robot model 70 P7 CRT-based SSTV monitor and the Robot model 400 digital scan converter. It is hard to believe that all three images are products of the same 8-second SSTV video standard.

Linux-based SSTV video generation software was created for the purpose of designing the TriplePIC scan converter and evaluating its performance. A test pattern consisting of a 25% wide vertical black bar followed by a 25% wide vertical white bar followed by an alternating pattern of black and white pixels having a density of 128 pixels per line was used to tune the video demodulator for a uniform response across the entire SSTV frequency spectrum. A second test signal employing a linear ramp that swept between black and white across each video line was also employed to ensure a high degree of linearity was maintained during the tuning process.

Figure 10 illustrates the results of the video resolution test. The data used to generate the plot was obtained from the TriplePIC's serial data interface. As such, it also reflects the performance of the first PIC's analog to digital conversion process. Data for a single line of SSTV video is plotted. About 2 dB of A/D sampling jitter is evident in the high frequency portion of the test signal. Some ringing in the demodulator is also evident after the low-frequency black-to-white video transitions.

Figure 11 illustrates MMSSTV v1.13A software's handling of the same test image, which was presented to MMSSTV in the form of a lossless (.wav) audio file. The rendered image was saved in a lossless bit mapped (.bmp) format, and each greyscale value across a single SSTV video line was plotted as a linear function of horizontal pixel position. Clearly, all high frequency video information is lost, and what remains is only a subharmonic of the actual video frequency. There is aspect ratio distortion present as well, since MMSSTV treats 8-second SSTV video as having a 4:3 aspect ratio rather than the accepted 1:1 aspect ratio defined by traditional SSTV standards. Like the Robot 400 scan converter, MMSSTV doubles the display of each SSTV video line to produce a pseudo 256 line image.

No vintage SSTV monitors or scan converters were available for similar evaluation, but few, it is believed, would fare well.

An SSTV video resolution that is flat to 128 vertical lines requires a demodulated baseband video bandwidth that is flat to at least 1038 Hz for SSTV scanned at a 15 Hz line rate, and 1164 Hz for video scanned at a 16.666 Hz line rate. Computer aided analysis of the post-detection lowpass filter employed in the Robot 400 scan converter revealed a 3 dB bandwidth of only 766 Hz. A slightly smaller bandwidth of 748 Hz was discovered for the Robot 70A SSTV monitor. At 1000 Hz, response is down nearly 8 dB (with respect to DC) in the Robot 70A, and nearly 10 dB in the Robot 400. These figures do not even take into consideration the further bandwidth restrictions imposed by the slew rate of the limiters, the frequency response of the video demodulators, and the speed and resolution of any A/D conversions (as in the case of the Robot 400).

It should also be pointed out that when performing SSTV to FSTV scan conversion, a flat video response from DC to 128 pixels per SSTV video line requires an FSTV video bandwidth that is uniform to over 3.2 MHz, taking into consideration the compression required to present the image in a 1:1 aspect ratio (pillarbox) format. Modern HDTVs appear to achieve this level of resolution with ease, but older displays may be pushing their limits.

Construction

The TriplePIC was constructed on a pair of 90x70 mm perforated circuit boards and housed in a Ten-Tec model BK-925 enclosure. There is no need to span the circuitry across two separate boards, except perhaps for testing purposes. There are no printed circuit board designs available for this project.

The entire scan converter operates on a single 5 volt supply and draws approximately 60 milliamps of current. U9, a 5-volt 3-terminal voltage regulator, allows operation on DC voltages greater than approximately 7 volts. Diode D5 protects the scan converter from reversed polarity input voltages, and along with capacitor C34, permits operation from a source of low-voltage AC. Due to its low voltage and current requirements, the TriplePIC can be efficiently powered by a series connection of four rechargeable NiCd or NiMH cells. Such an arrangement would permit its use in portable and/or EmComm environments.

Five percent tolerance metalized polyester film capacitors, along with quarter-watt dissipation, five percent tolerance carbon film resistors were used throughout all of the TriplePIC's circuitry.

All DIP integrated circuits were installed in machine tooled low-profile sockets. U12, a PIC16F76, requires a skinny (300-mil wide) 28-pin DIP socket. U14, an OPA2365, is in an SOIC package, and was tack-glued to the circuit board with short lengths of #30 enameled wire soldered directly to each pin.

The rear panel of the enclosure provides access to all scan converter I/O ports. Operating power for the scan converter is delivered by way of a Size M 5.5 mm O.D. by 2.1 mm I.D. chassis mounted coaxial power connector. RS-232 data is made available to peripheral devices via a female DE-9 (a.k.a. DB-9) connector. Female RCA jacks were used for all other external I/O connections. The SSTV video input jack was wired in parallel with an adjacent RCA jack so that SSTV signals could be looped through the scan converter and exported to other peripherals.

Firmware for all three microcontrollers was written in PIC16 assembly language under a Slackware Linux environment. "gpasm", available from http://gputils.sourceforge.net/, was used to assemble the firmware for each PIC and produce Intel HEX output files. "picprog", available from http://www.iki.fi/hyvatti/pic/picprog.html, was used along with a simple serial port programmer designed by Jens Madsen (http://www.jdm.homepage.dk/newpic.htm) to read each HEX file, and burn the firmware into the appropriate microcontroller.

A website at http://www.qsl.net/kd2bd/TriplePIC.html has been established to disseminate the TriplePIC's firmware and related information. In an effort to permit and encourage experimentation in vintage SSTV and to help further the evolution of the TriplePIC scan converter, all firmware associated with this project has been released under the GNU General Public License.

Alignment and Operation

The only alignment involves adjusting trimpots R62 and R63 associated with the LM555 oscillator to produce an output of

4151 Hz for reception of 15 Hz SSTV, and 4654 Hz for 16.666 Hz SSTV. Output from the oscillator can be measured on Pin 3 of the LM555. Should the TriplePIC display SSTV images having any degree of line-to-line jitter when receiving video from a clean, stable source, a slight re-adjustment of these trimpots will eliminate the instability.

When the TriplePIC is first powered on, the random bit patterns present in the video RAM chips will be read out by the PIC16F76 microcontroller and displayed on the FSTV monitor. This pattern is quickly wiped away by a greyscale pattern that is written into video RAM by the PIC16F77 as part of a power on test. This pattern is overwritten by a second (reversed polarity) pattern that is generated within the PIC16F88. Successful display of this pattern validates proper serial communications between the first two PICs. Since the second pattern is produced within the PIC16F88, it is also delivered to any peripheral devices connected via the RS-232 port. After the second pattern is fully displayed, the TriplePIC is ready to receive and process SSTV images.

The TriplePIC scan converter follows a "triggered sweep" method of operation. That is, the initiation of every slow-scan horizontal and vertical sweep is made only after successful reception of sync is made at the time it is expected to occur. This method of operation avoids having the last video frame from being immediately overwritten by a non-stop SSTV raster scan, which would be the case if a continuous sweep methodology had been employed. It also prevents the TriplePIC from filling the FSTV display with out-of-sync SSTV video.

LED D4 serves as a sync indicator, and flashes when SSTV sync pulses are being received. A steady 1200 Hz input tone will cause the LED to light continuously.

If a vertical sync pulse is missed during reception on an image, the SSTV vertical sweep can be reset manually by pressing push button SW1. SSTV reception can be suspended by closing switch SW2. This action also freezes the current image on the FSTV display. Opening switch SW2 resumes SSTV reception, and initiates a new vertical sweep at the top of the FSTV screen.

Going Further

Purists may insist that vintage SSTV should only be viewed on P7 phosphored CRTs. The TriplePIC allows several methods for doing this that will yield results superior to any P7 SSTV monitor design to date. Demodulated vertical sync, horizontal sync, SSTV baseband video (only), and composite baseband SSTV video (including sync) are available through the TriplePIC's demodulation circuitry for application to video amplifiers, sweep circuits, and deflection amplifiers of a designer's choosing.

A better approach is to obtain SSTV video and sync through the TriplePIC's serial port. By applying the TriplePIC's serial data to a microcontroller (such as a PIC16F77 running at 3.6864 MHz), and following it with several D/A converters, separate SSTV video, horizontal, and vertical sweep waveforms can be easily generated. These can be followed by video and sweep deflection amplifiers to drive a P7 CRT. The firmware required for doing this could be adapted from what is currently employed in the TriplePIC's PIC16F77 microcontroller.

Lowering the TriplePIC's LM555 oscillator frequency to approximately 1995 Hz by adding a third trimpot, an additional position to switch SW3, and modifying the PIC16F77's firmware accordingly will permit reception and display of quarter-speed (7.5 lines per second) 256 line high-resolution SSTV images.

Finally, a pure hardware approach to SSTV video generation needs to be developed to permit the transmission of SSTV images in real-time. Perhaps the sweep rates of a CCD camera could be modified for this purpose, or a high-quality FSTV to SSTV scan converter could be developed to compliment the TriplePIC. The challenge is yours.
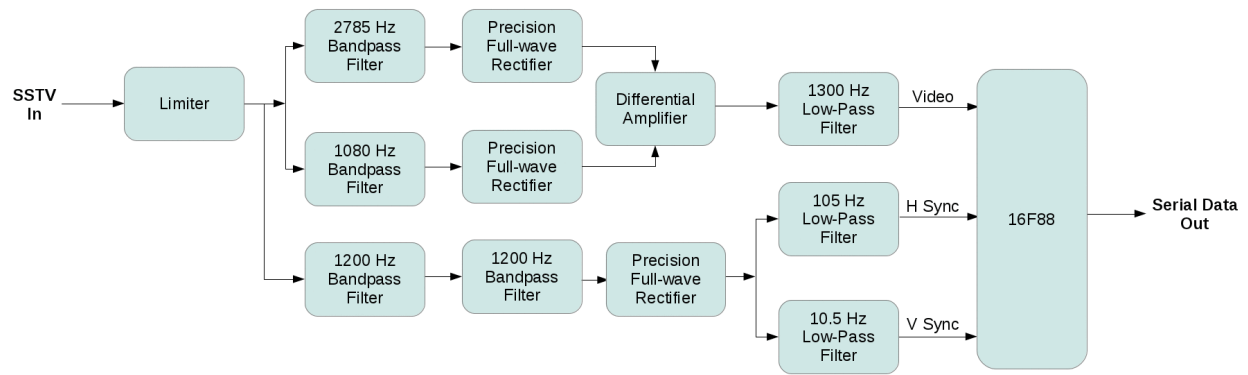
Dedication

This article is devoted to the memory Copthorne MacDonald, PE, who passed away on December 20, 2011. Cop was born in Chicago in 1936, was first licensed as a Ham in 1951, and was a 1958 graduate of the University of Kentucky where he majored in electrical engineering. Cop was the inventor of Slow Scan Television (SSTV) while a student in college.

Cop was a Communications Systems Engineer and Professional Writer, and last resided in Rice Point, Charlottetown, Prince Edward Island, Canada.

Cop held a variety of callsigns during his 60 years as an Amateur Radio Operator, including W9OLS, W4ZII, WA2BCW, W0ORX, VE1BFL, and VY2CM.

The author also wishes to recognize Mr. Phillip Carpenter, W4RTX, who kindly offered to review this article prior to its initial publication. Not only did Mr. Carpenter provide many valuable suggestions, but he also very generously provided a classic Robot model 70 SSTV monitor for my advocacy and continuing work in the field of vintage slow-scan television.

TriplePIC SSTV Video and Sync Demodulation Circuitry

Figure 1: Functional Block Diagram of the TriplePIC's SSTV Video and Sync Demodulation Circuitry

TriplePIC SSTV Digital Video Processing and Scan Conversion Circuitry

Figure 2: Functional Block Diagram of the TriplePIC's SSTV Digital Video Processing and Scan Conversion Circuitry
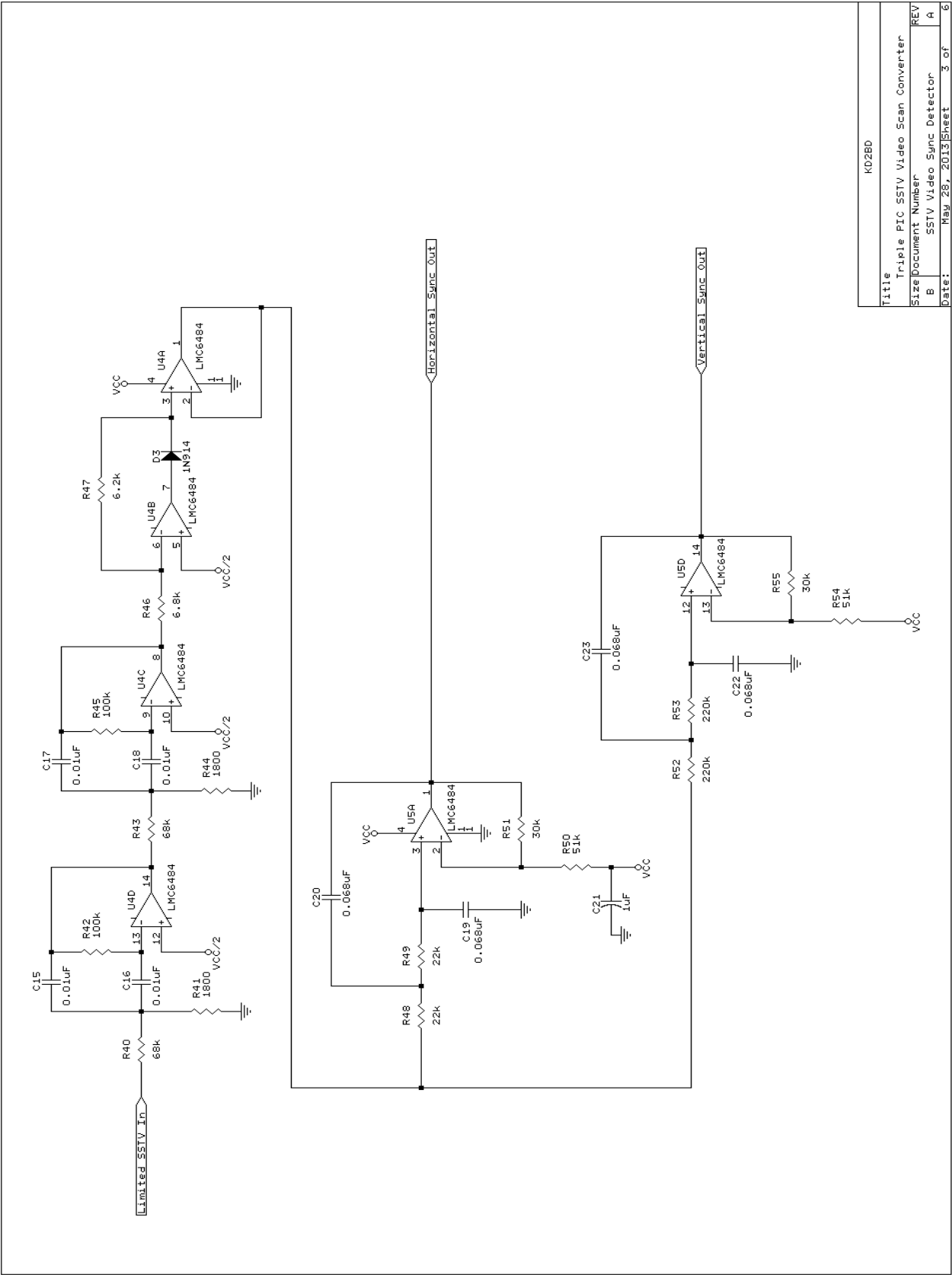
Figure 3: The TriplePIC's SSTV Video Discriminator Circuitry

Figure 4: Post Detection SSTV Low-Pass Filter and Video Amplifier Circuitry

Figure 5: SSTV Video Sync Detector and Sync Separator Circuitry

Figure 6: Input Supply Voltage Conditioning and Demodulated SSTV to High-Speed Serial Data Converter Circuitry

Figure 7: FSTV Video RAM Address Counter, D/A Converter, and FSTV Video Generation Circuitry

Figure 8: FSTV Video RAM Circuitry – Two 32k static RAM chips are multiplexed to form 64k bytes (256x256 pixels) of total video display memory.

Figure 9: 120 Line SSTV Resolution Comparison – The Robot 70 and Robot 400 images were taken from old magazine ads. The TriplePIC image is a photograph taken from the CRT of a 13" color FSTV fed by the TriplePIC through an RF video modulator.
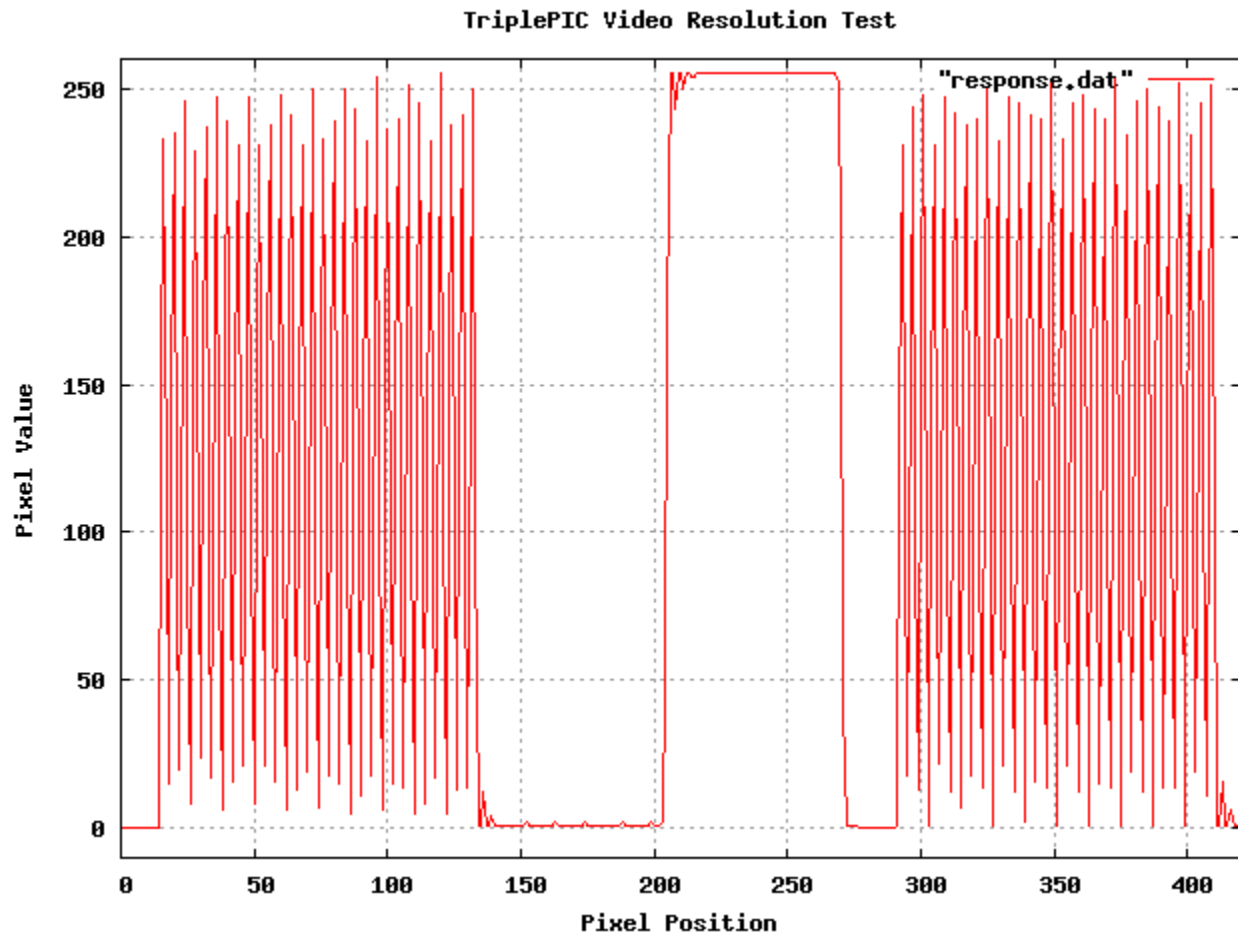
Figure 10: Video resolution test illustrating the TriplePIC's response at 128 pixels per line relative to its low video frequency response. A pixel value of 1 represents black while 255 represents white. There are 256 pixels per video line.
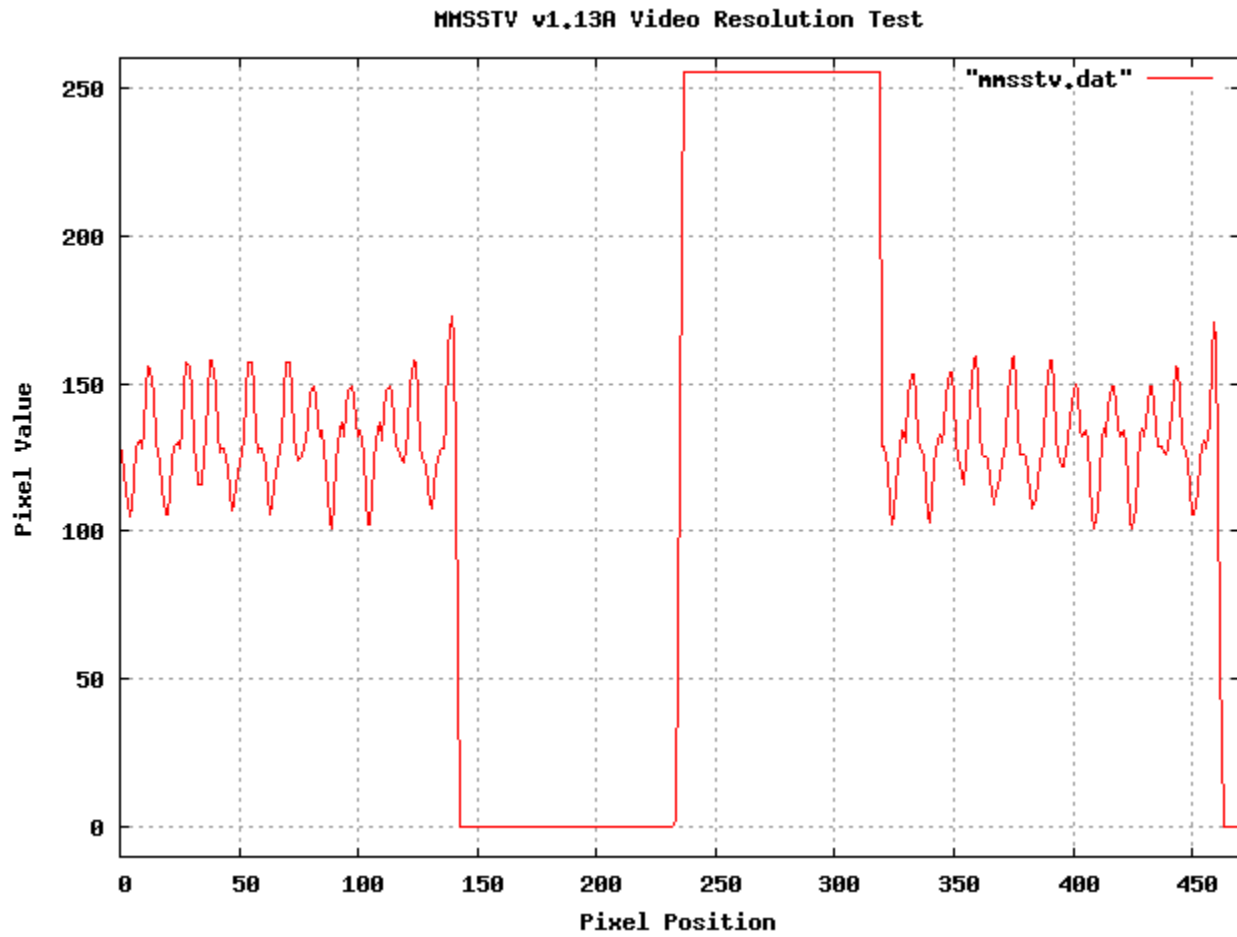
Figure 11: Video resolution test illustrating MMSSTV v1.13A's response at 128 pixels per line relative to its low video frequency response. All fine picture detail is lost, and the image is expanded horizontally by 33%.
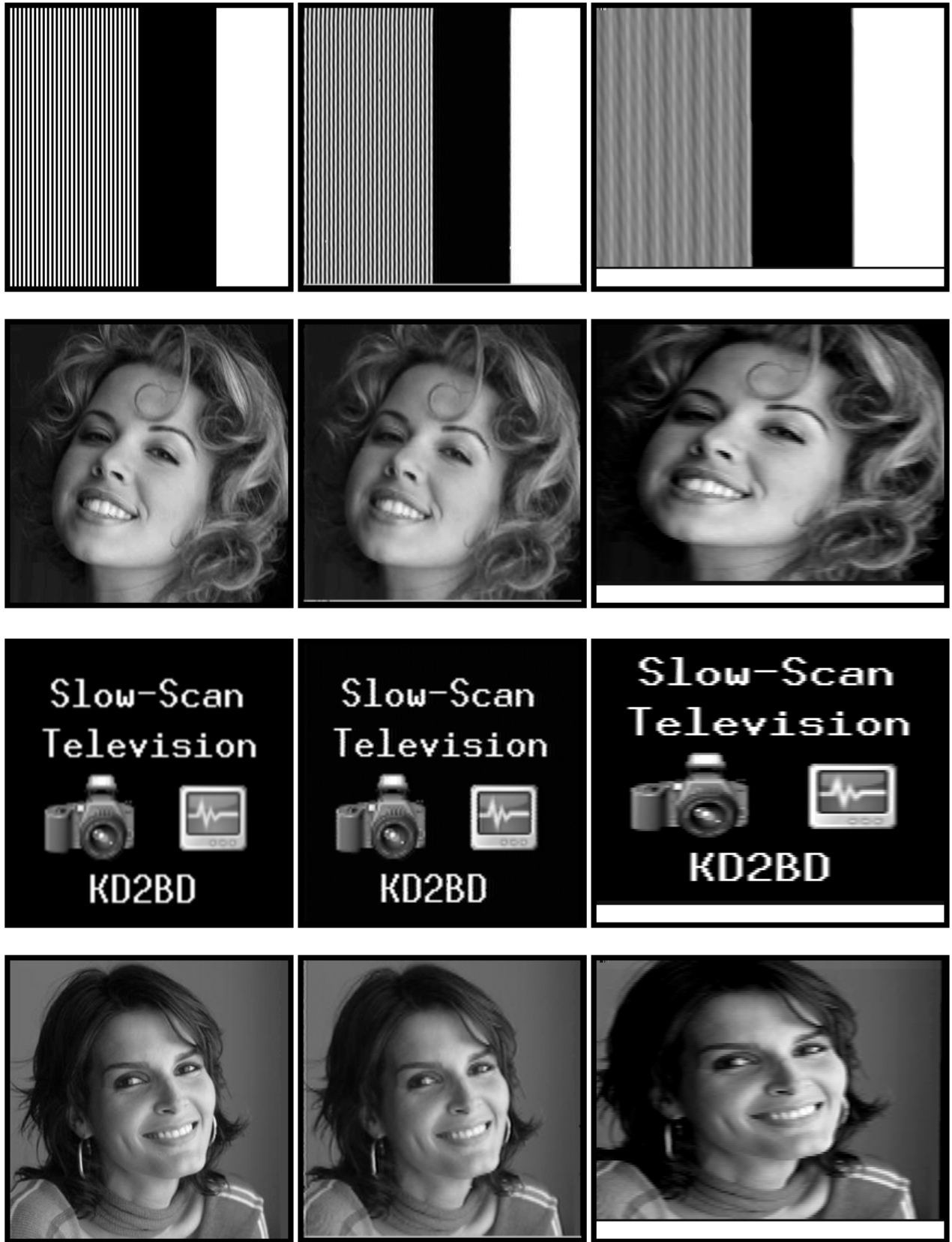
Figure 12: A Comparison Of Closed-Circuit Image Quality – Original vs. TriplePIC vs. MMSSTV rendered images.
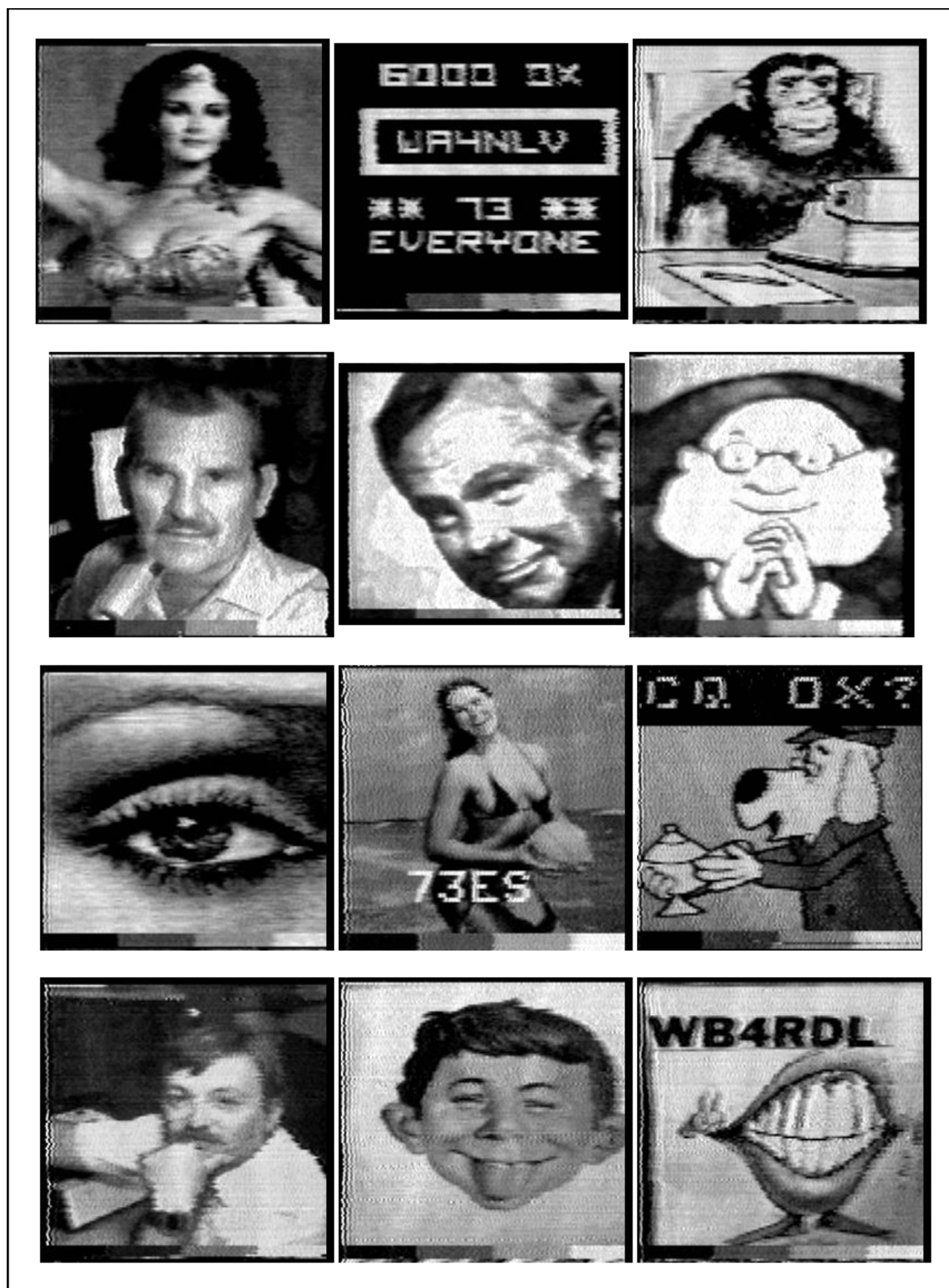
Figure 13: TriplePIC rendering of vintage SSTV images captured on audio cassette tape by the author circa 1980.