Animac: Analog 3D Animation

by Walter Funk

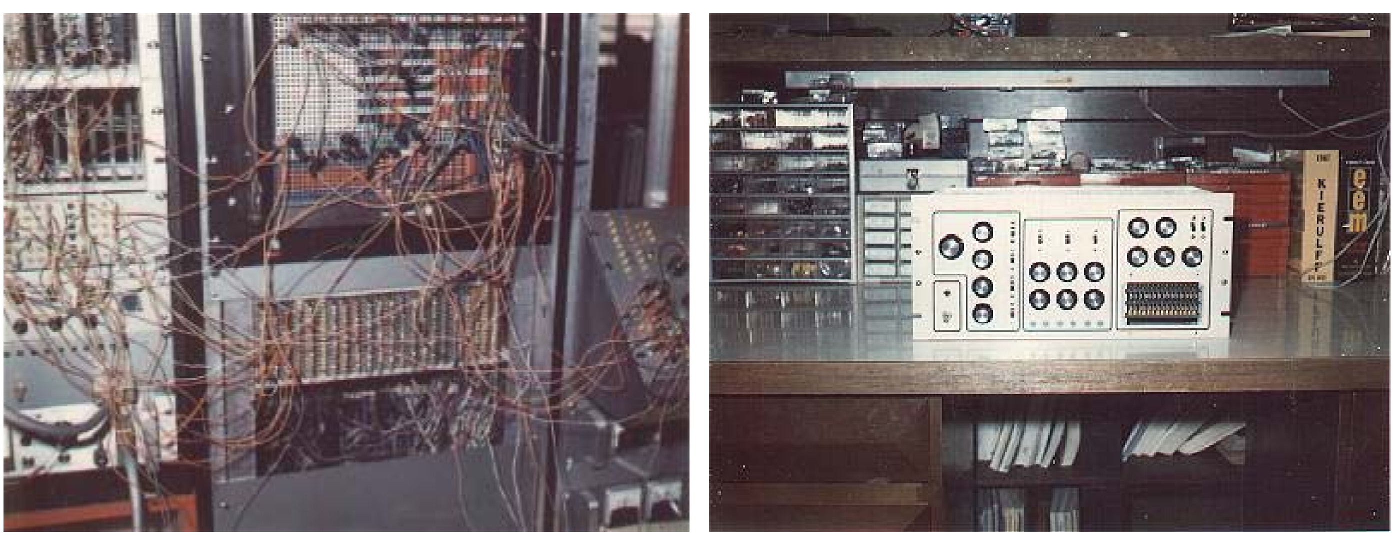
Walter Funk has been producing autostereoscopic movies since 1994, pioneering the artistic use of volumetric and autostereoscopic displays for entertainment. His Hologlyphics performances involve volumetric animations and live music performed for an audience. He founded Hologlyphics (http://www.hologlyphics.com), bringing live volumetric entertainment to film and video festivals, museums, art shows, and live music events. Walter studied holography at The Holography Institute and music at the Center for New Music and Audio Technology, UC Berkeley.

Without polygon modeling software or even a CPU in sight, The Animac produced complex 3D animations unlike anything else in its time. Beginning in the late 50s as The Bone Generator, it evolved into the Animac in the late 60s. This 3D animation system was not commercialized nor widely used. A less flexible, 2D subset of this system did make it into a quite successful commercial product. If you've seen Star Wars, Logan's Run, or Electric Company, you've seen the results of its two-dimensional descendant, the Scanimate.

Animac was developed by Lee Harrison and members of his team. The first version, working in 1959 between Christmas and New Year, had eight “bones”. It was just a piece of aluminum mounted on a board with circuits behind. The second one in 1960 had 16 “bones” and a big power supply underneath, all in a wooden rack. This was developed until around 1964. Then in1967 it was updated from tubes to transistors.

While Lee was in college, he always loved animation. One day in a class he “met” an oscilloscope, and something clicked in his head about animation. It said, this is that way it will be done. Then in 1959, his senior year, he read a paper on fake color by Bill Altimus who worked for the Philco Corporation. So Lee got a job at Philo, and was lucky enough to work in the lab with Bill Altimus. There he formed the first of many teams to work on this animation machine.

Animac's 3D animation creation was carried out with a patch panel, potentiometers, joysticks, dance interfaces, switches, and a flying spot scanner. Analog and simple digital circuits were patched together physically through the patch panel, representing 'bones' of a human body or other objects the artist wishes to animate. Bones are basically wire-frame line segments. “Surface Characteristics” can be mapped via “spinning vectors” called Skin, which are actually high frequency sin/cosine oscillators.



Left: Animac's patch panel. Right: Animac's control panel.

The output of these circuits created the three electronic signals representing the animation's image. This 3D output was further transformed by an additional electronic circuit block called the "Camera Angle Network". The Camera Angle Network allows the animator to control the perspective of the animation scene. Under animator control, it electronically transforms the image's three signals into two signals representing a 2D perspective of the 3D animation scene. The output of the two signals representing the scene was sent to an oscilloscope. The image was then filmed and filters were placed in between the oscilloscope and the camera, allowing for color.

Two basic elements allowed the creation of figures and shapes. The first element is called a Bone, which in many cases but not all represents a bone in a human or animal body. The Bone is a spatial vector, a line in 3D space which has a determined starting point, length and direction. Skin is thought of as the thickness, shape, texture or surface characteristic of the Bone, serving multiple functions. The Skin rotates or spins orthogonally around the length of the bone.

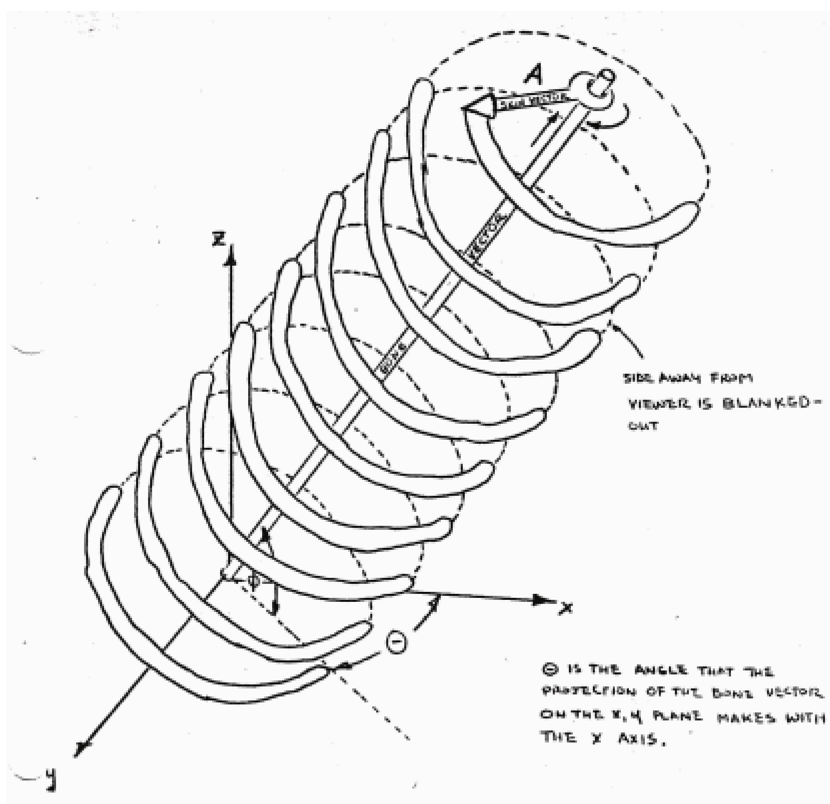
Before delving into how the device created 3D animations with Bones and Skin, I should mention the analog circuits and their application to 3D animation may not be familiar to everyone in the current field of digital 3D animation. The actual circuits (i.e. circuit design) will not be discussed, only their function. At the end of this article are several pages of block diagrams and a signal flow chart. Please refer to these for reference, if needed.

It should also be noted the programming interface in most instances is quite awkward. Likely the result of completely pushing the artistic envelope, with the limit of the technology at the time. There simply WAS NO elegant interface for programming these 3D transformations available. A very elegant and charming control interface however, was developed for controlling programmed human characters.

The entire system was driven by a master oscillator, acting as a master clock. The clock supplies the driving signals to the device and also allowed the inner workings to be time synchronized. The master oscillator is a 12,288 Hz sine wave whose output is shaped into a square wave for the timing signal and also through a 90 degree phase shift network whose output now becomes a cosine wave.

The square wave output is fed directly a counter for event and frame rate timing. It is also the driving signal for the horizontal deflection generator of the skin scanner, to be described later. The sine and cosine waves are fed into two separate sets of sample and hold circuits, are also fed into a pair of multipliers.

The counter is a chain of nine bistable multi-vibrators, each stage divides the clock rate frequency by 1/2. So the output of the first multi-vibrator is ½ the clock frequency, each additional stage halves the clock frequency. The output of the last stage is the clock frequency divided by 512. Thus for a frame rate of 24 frame/sec the high frequency must be 12,288 Hz. The frequency of the clock may also be increased to allow a 30 FPS frame rate. The higher the frequency, the greater the image resolution will be.



Showing the Bone vector, from original technical drawing.

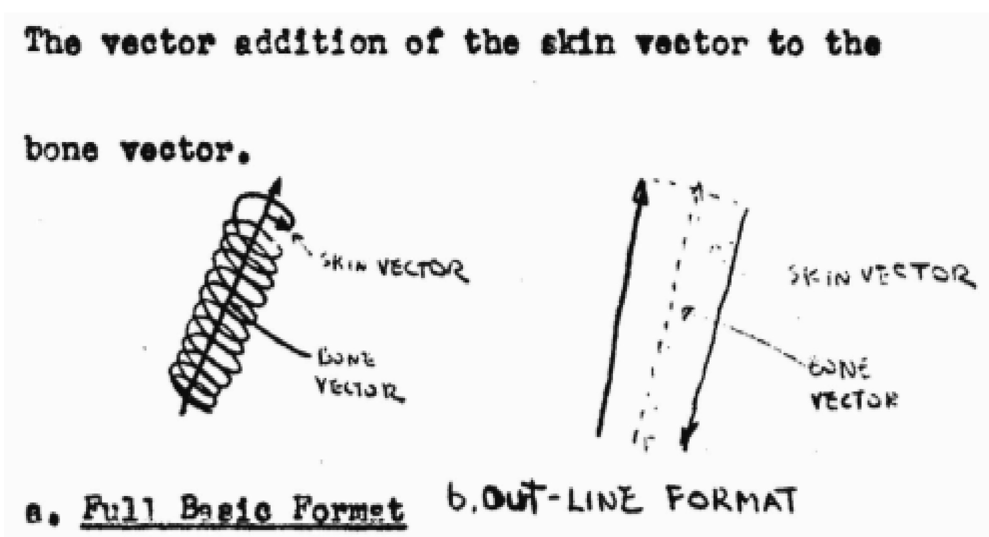
The Bone Generator is the heart of the analog 3D animation engine. Bones are defined by a starting point in xyz space, its direction and how long in time it travels. Time was used as the basis to determine the length of a bone. The frame rate clock waveform was used to open and close a series of gates in a sequential manner, programmable by a patch panel. While the bone was turned on, specific gates would open and the gates would have DC values determining the starting point, X, Y, Z, of that bone. The length was determined by physically patching into a timing circuit or a counter, which was reset after each bone. A chain of mono-stable multi-vibrators, called the MSMV chain, drives the sequence of bone-gates. The input to the first MSMV in the chain is a frame rate frequency pulse, such as 24 Hz, which comes from the counter.

The bone generator has three integrators, one for each geometric coordinate of 3D space. This allows for smooth ramp functions from the DC values, for drawing straight lines. The capacitors of the integrators can be shorted out or discharged at desired times during the sequence of bones and at the end of each cycle of bone generation. Discharging of the capacitors causes the beam of the display CRT to fly back to the starting position. When the animator started a bone they also started a counter, and a flip flop was plugged into the counter and when it got up to the count it would turn that bone off. Once a bone ends, the Generator can draw another bone from the ending point, fly back to a navel point, or actually turn around and go back the same way. To program it there was a patch panel that determined the pattern or order in which the bones were drawn.

In synchronization with bone generation is The Skin Network. This allows spinning vectors around the straight line segment, of a distance variable over the length of the line. In addition the spinning vector can be rotated. The function of the skin network is to algebraically combine the various voltage representations of the 3D image. Two algebraic functions are performed by that portion of the device, multiplication and addition. That calculates the orthogonal angle to the Bone. The distance from the Bone can be modulated by other signals, determining skin thickness and texture.

The Skin Generator was used for scanning and storing skin features such as color, texture, and shading. The function of The Skin Generator is to generate a video signal whose magnitude represents the orthogonal distance or thickness between the bone vector and the surface of the skin. A flying spot scanner recorded light intensity signals from specially prepared photographic transparencies.

The flying spot scanner's controlling horizontal and vertical deflection sawtooth wave forms are driven by an input from the clock. The pattern of movement of the spot of the scanner is basically rectangular, with some localized modifications in the pattern for special skin distortion effects as in lip, eye, and other facial and “plastic" type movements. Wrinkle effects can also be automatically developed as a function of associated bone angles.



Adding the skin to the bone, from original technical drawing.

Once the 'Skin' is added to the images 'Bones', the three signals representing the 3D images are converted into two signals representing a 2D perspective of the image, via an analog 2D projection method. This part of the Animac is called the Camera-Angle Network.

The function of the Camera-Angle Network is to algebraically combine, thus geometrically and vectorially combing, the x, y and z components of the three-dimensional figure. Rotation of the xy plane about the x axis and also xz plane about the z axis is possible. This allows for the selection and presentation of any 2-dimensional projection or view of the 3D figure when the outputs of this network are presented to the horizontal and vertical channels of a display CRT. The two signals represent the “beam-positional" information necessary to draw the figure.

The two rotation function of the Camera-Angle Network are controlled by potentiometers. Controlling Servos can be used to position the shafts of the pots so that the servo driving signals may be recorded on the control tape (magnetic) along with other control signals, thus recording the camera angles. The servos will automatically position the shaft of the pots to give the desired viewing or camera angles on playback. The servo signals are recorded between frames.

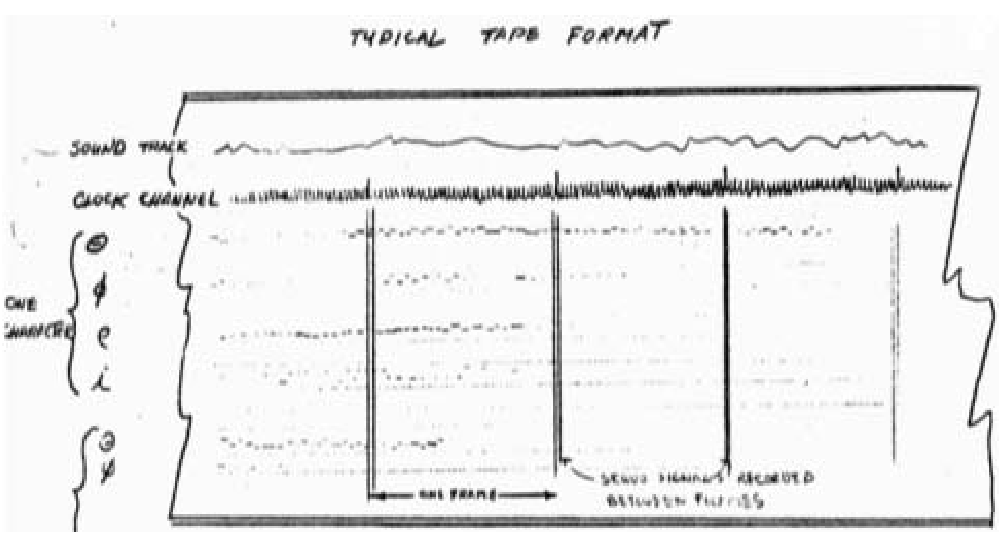
Harrison also developed an analog method for hidden line removal. A special device for “overlap prevention” had the function of doing away with a “ghost” image or overlap. Overlap is classified into two types.

- One type occurs when the “back part” or other parts part of the image, on the side away from the viewer, is drawn. This overlap is prevented by turning off the intensity of the beam according to the vectorial position of the skin vector which is a function of 1) phase of the higher frequency, and 2) the camera angle, which governs the position of the plane of projection.
- The 2nd type of overlap occurs when one part of an object or figure overlaps another part, or where one figure is in front of another. This was dealt with via a multi-gun CRT, with synchronized “write” and “erase” guns. The 'erase' gun has selective erase capability. Both guns received the same positional XY signals for CRT beam deflection, with the erase gun preceding the write gun by employing a slight delay in the “write” signals.

For recording animations, the “Recording Network” is to record the joined together gate output signals (multiplexed angle-signals from the bone-gates) and allow for the playback of these signals. The recorder is a multi-channel recorder. On one channel is used to record the clock signals and frame signals for synchronization. The clock channel records the high frequency sine wave plus an intermittent frame pulse. The signals are electronically separated upon playback. The sine wave is sent to the Bone Generator and the frame pulses are sent to the counter chain.

Sound was recorded on another tape channel. Other channels could be used to record and control other parameters of the bone. For example, an additional channel could be used to control the rotational position or twist of the skin relative to the bone axis. Selective recording of individual gate-outputs is accomplished with “recording gates”, 'which are activated (opened) by the multi-vibrators associated with the bone-gates desired to be recorded.

The electronic signals coming out of the camera angle network are beam-positioning signals, just as fingers control the position of a pencil and paper. The function of the shading and color network is to govern the beam intensity as it draws the figure or object. High frequency variations in intensity are produce skin shades and shadows, textures etc. which arise from the surface variations in the skin.



Animac's tape format, servo signals can be recorded between frames

For color, three CRTs could be used, each with a separate color filter. The CRTs can be sent the same electronic beam positional signal and then be optically superimposed. By varying the intensities of the 3 CRT beams, the animated image has full spectrum color capability.

The "skin" video signal obtained from the "Skin Generator" contains information about the orthogonal distance between bone and skin (thickness). Electronic variations of this video signal are used to control the brightness (shading) and also create other effects.

To accentuate skin features which occur between the edges of the object being drawn, a rate-of-change signal is obtained by differentiating the skin video signal. A threshold network detects all rates of change above a prescribed absolute value. The clipped output of the threshold network is amplified and scaled, then used to modulate beam intensity.

Rounding, edge effects (edge shadows, etc.) are produced in accordance with the skin vector position, which is a function of the phase of the high frequency clock. In addition, a high frequency wobble or a focus-flare effect may be employed to heavy-up or thicken the edges, this action also being synchronous with the phase of the high frequency sine wave.

By controlling the voltage inputs to the bone gates, the brightness, positions, attitudes, plastic distortions, and other special parameters can be controlled. The controlling signals are very low frequency and in some cases practically DC. Networks of variable resistors and very low frequency generators may be used to generate interrelated bone-group actions or motions.

Shaped waveforms in place of DC inputs into the bone gates generated bones that were not straight. A triangle or saw-tooth control input makes wiggly bones, a sinusoidal input if at the proper phase and frequency makes a circular bone, a square wave will make a zigzag bone, and a ramp wave can produce curved or arched bones.

Joy-sticks and finger controls have been designed for easy, mechanical manipulation of the controls. Facial expressions may be input from actual facial and lip motions using a network of strain gauges. Potentiometers and Lincoln Logs were used as armatures, to build a dance control interface called the Animation Harness. It was worn by a live dancer, and converted tactile motion into control voltages which could make the animated character dance in real-time.

Animation Harness on dancer, real-time animation.

Overall operation was divided into five general steps called "Modes", although many variations on the order of procedures could be devised.

- **Mode I: Character Information Input:** The transparencies from the Skin Generator are fed into the device. The corresponding Bone Lengths are set via hand, potentiometers, or pre-programmed resistor cards. Bone sequence is programmed, including flyback, by making desired interconnection of the MSMV chain via the patch panel.

- **Mode II: Set Up:** The primary set-up-control potentiometers are adjusted to place the character or characters in a desired neutral position. The primary recording gate switch is closed and the recorder is activated to record a length of time corresponding to the scene length, which is governed by the pre-recorded sound track. The tape is then returned to its starting position. This may be called the initial tape pass.
- **Mode III: Animation:** With the initial recording gate open, but with the desired bones in the record mode, animation is effected by adjustment (either electronically, electro-mechanically, or by hand) of the bone gate inputs of the bones being animated. This may be called the animation pass.
- **Mode IV: Full Animation Check:** In this mode, the device is ran at a slower speed to allow the complete fabrication of the scene, including skin drawing, shadings, background superposition, etc., for inspection of the completed scene.
- **Mode V: Photographic Recording:** The device is run at the slower, photographic-recording speed while the individual frames of film are exposed to the sequence of pictures

And then you're done! It was that simple. If confused, again you may refer to the block diagrams and signal chart at the end if this article.

Animac was truly one of the very first electronic 3D animation systems. Experimental films were made and survive, but it was never used commercially. Animac did however provide the framework and foundation for future machines that received notable commercial use. Scanimate and CAESAR are both second-generation descendants of ANIMAC. Scanimate was in some ways a fixed version of ANIMAC, but with only 5 bones and 2D capability. CAESAR was similar, but under computer control and capable of keyframe animation.

With Scanimate, bones could be comprised of five separate video rasters, allowing drawn artwork to become incorporated. Artwork would be placed onto a light table and captured with a camera. The image could then be transformed by Scanimate before being displayed on a CRT and re-scanned with a monochrome NTSC video camera. Electronic colorizers were also employed, since the CRT was monochromatic.

As mentioned Scanimate was a very successful system, and has been used in countless TV shows, commercials and films. Many patents were granted for its underlying processes. In many ways it helped revolutionize animation, because things could be done in real-time.

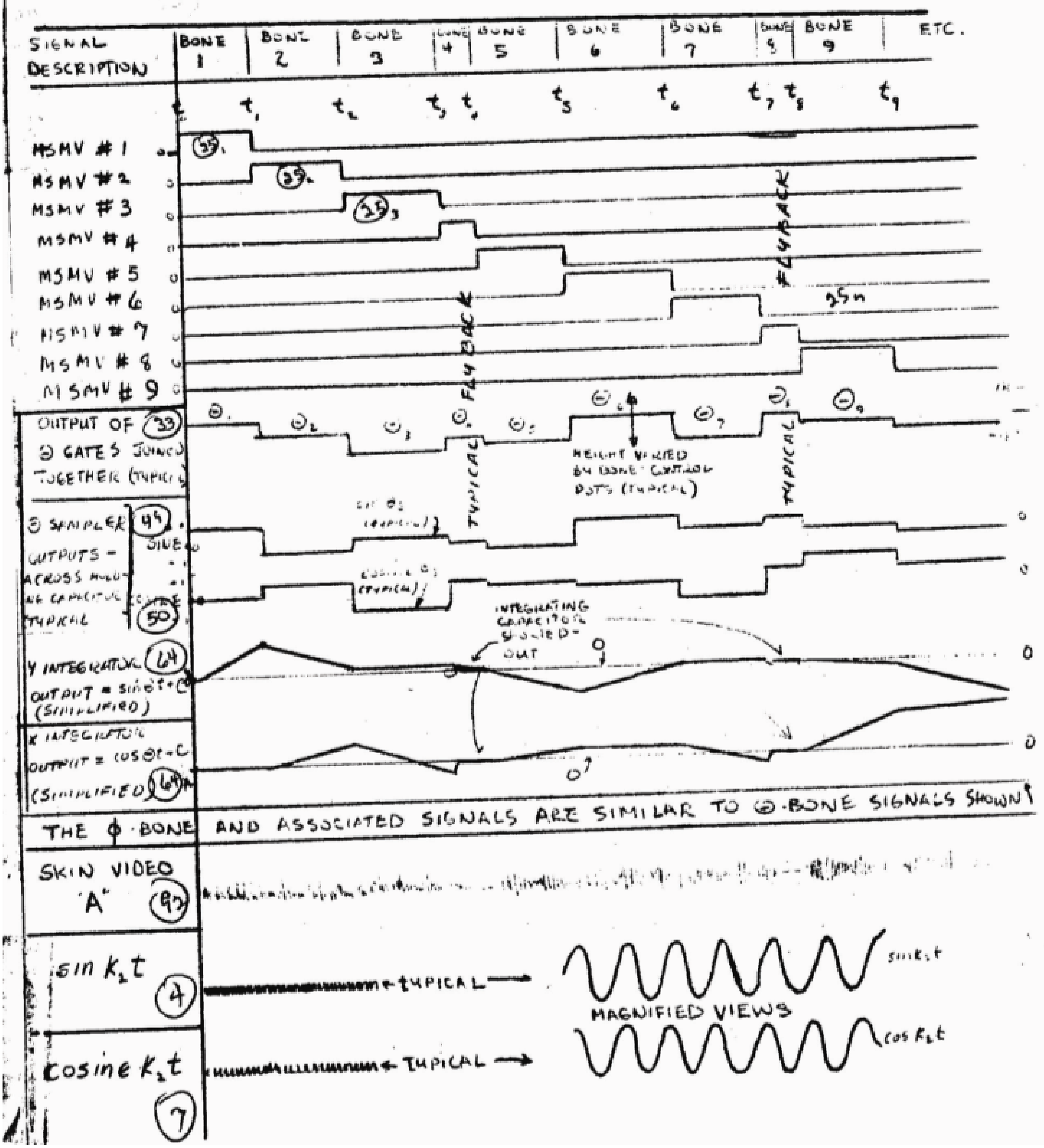
That climb to success took many years and was many times a struggle, but Lee Harrison kept going. Around 1962, he tried unsuccessfully to see if NASA was interested in this technology.

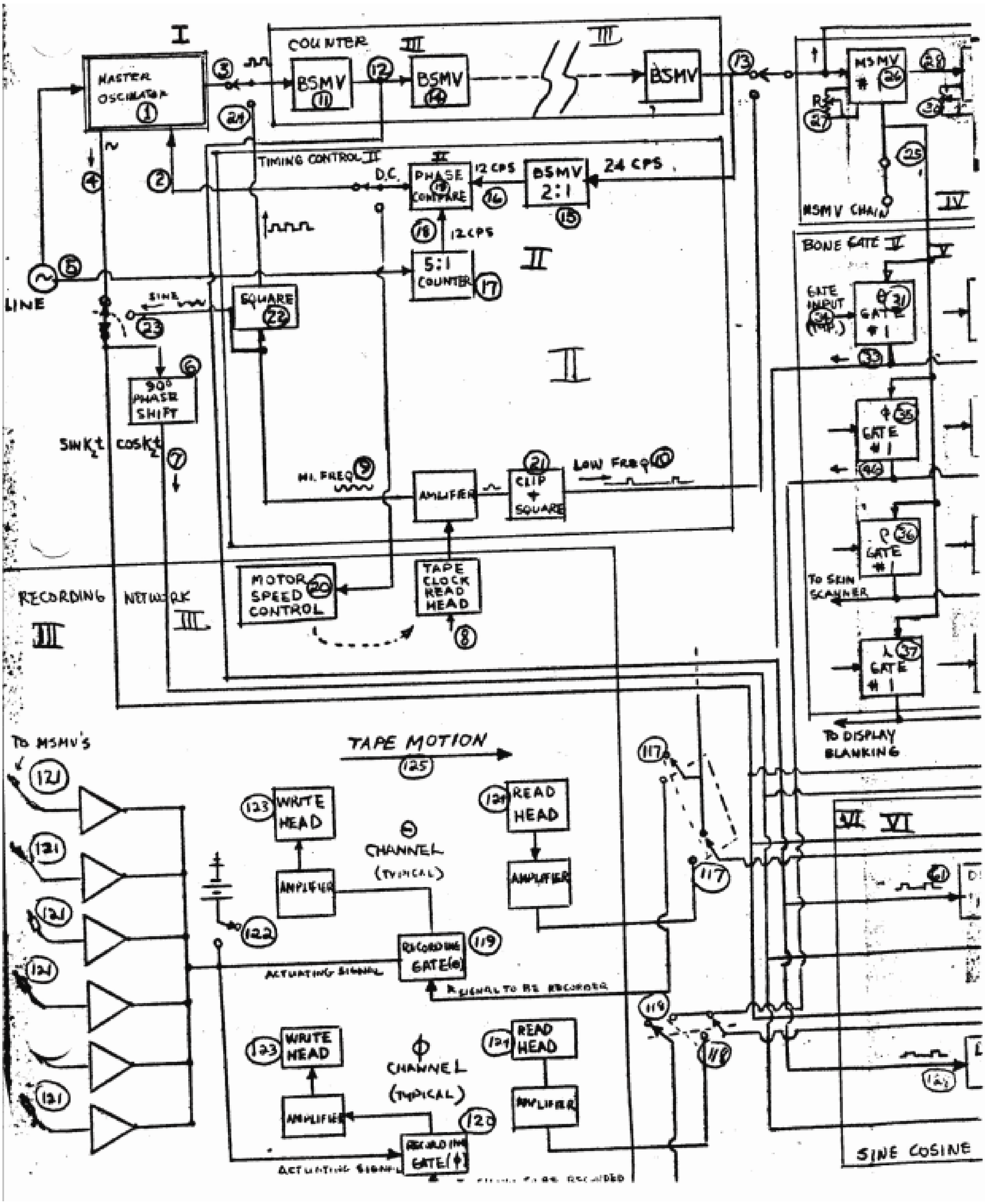
In Lee Harrison's own words, "I called them up and I asked them if they would be interested in getting a picture back of the astronaut in space using very low band width which says a lot to people who are interested in that stuff. Maybe voice band width. I'd done a few calculations on it and they said "Yeah, we're interested. How many cameras do you use?" I said, "None." They said. "What are you crazy?" I said, "Look, you already know what the guys look like. That's a prior. You could store that. You put it all together on the ground. You store what he looks like on the ground and you recreate that based on what's he doing up in space but what's he's doing you can detect with little detectors at his joints in the suit or whatever."

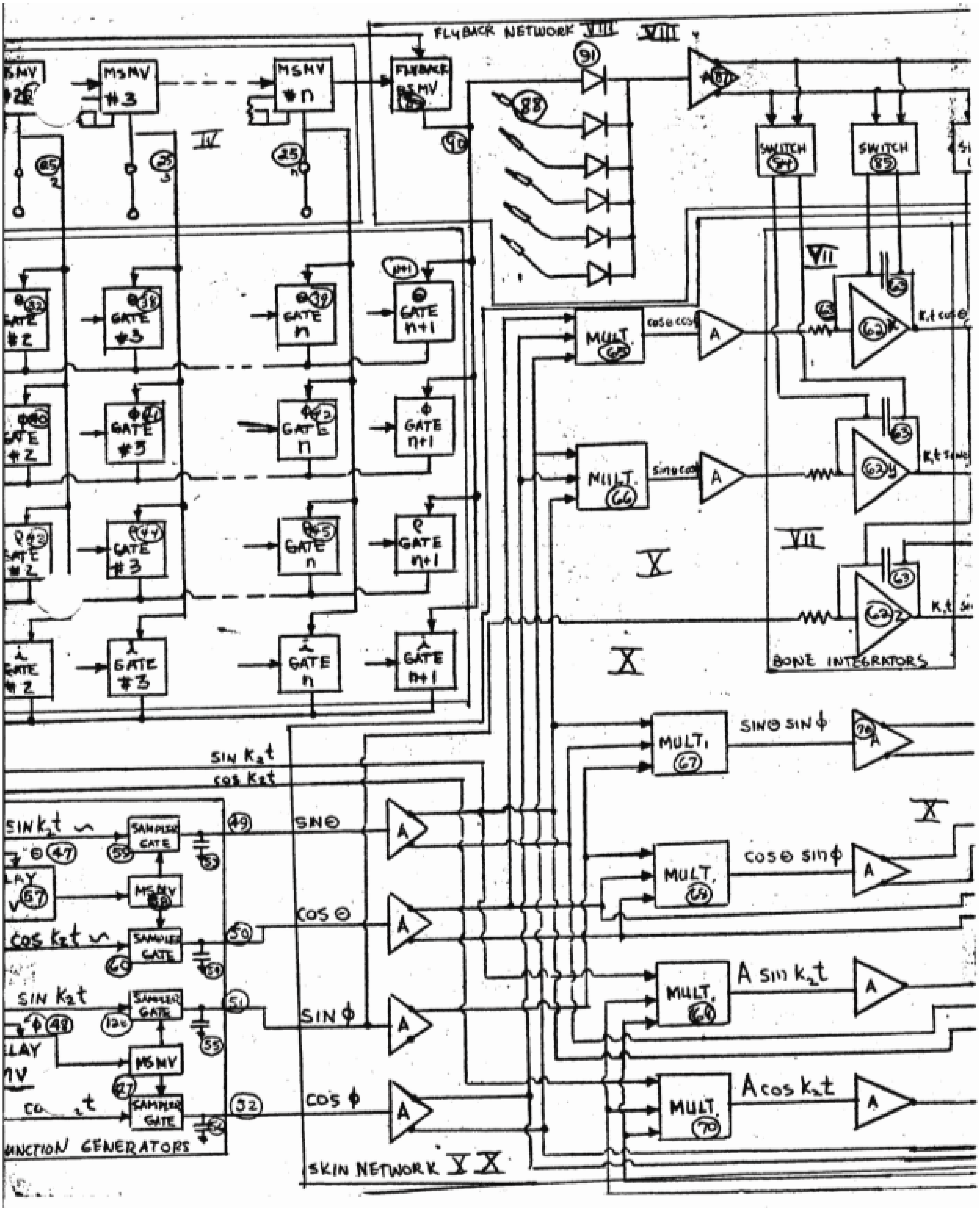
And NASA said, "You're crazy because you can't do it without cameras." And Lee said, "Well, I think you can."

Animac's block diagrams & a signal chart are show on the next four pages.

To show the inter-relationships of the various signals as a function of time, a signal plot is given below.




MASTER OSCILLATOR
COUNTER
BSMV
TIMING CONTROL
PHASE COMPARE
12 CPS
24 CPS
BSMV 2:1
5:1 COUNTER
LINE
SQUARE
90° PHASE SHIFT
HI. FREQ
AMPLIFIER
CLIP + SQUARE
LOW FREQ
MOTOR SPEED CONTROL
TAPE CLOCK READ HEAD
RECORDING NETWORK
MSMV
MSMV CHAIN
BONE GATE
GATE INPUT
GATE #1
TO SKIN SCANNER
TO DISPLAY BLANKING
TO MSMV'S
TAPE MOTION
WRITE HEAD
READ HEAD
CHANNEL (TYPICAL)
RECORDING GATE
ACTUATING SIGNAL
SINE COSINE


FLYBACK NETWORK VIII
VIII
MSMV #3
MSMV #n
FLYBACK MSMV
SWITCH 84
SWITCH 85
GATE #3
GATE n
GATE n+1
GATE #2
MULT. 65
MULT. 66
MULT. 67
MULT. 69
MULT. 70
SIN θ SIN ϕ
COS θ SIN ϕ
A SIN k2t
A COS k2t
BONE INTEGRATORS
SIN k2t
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SIN ϕ
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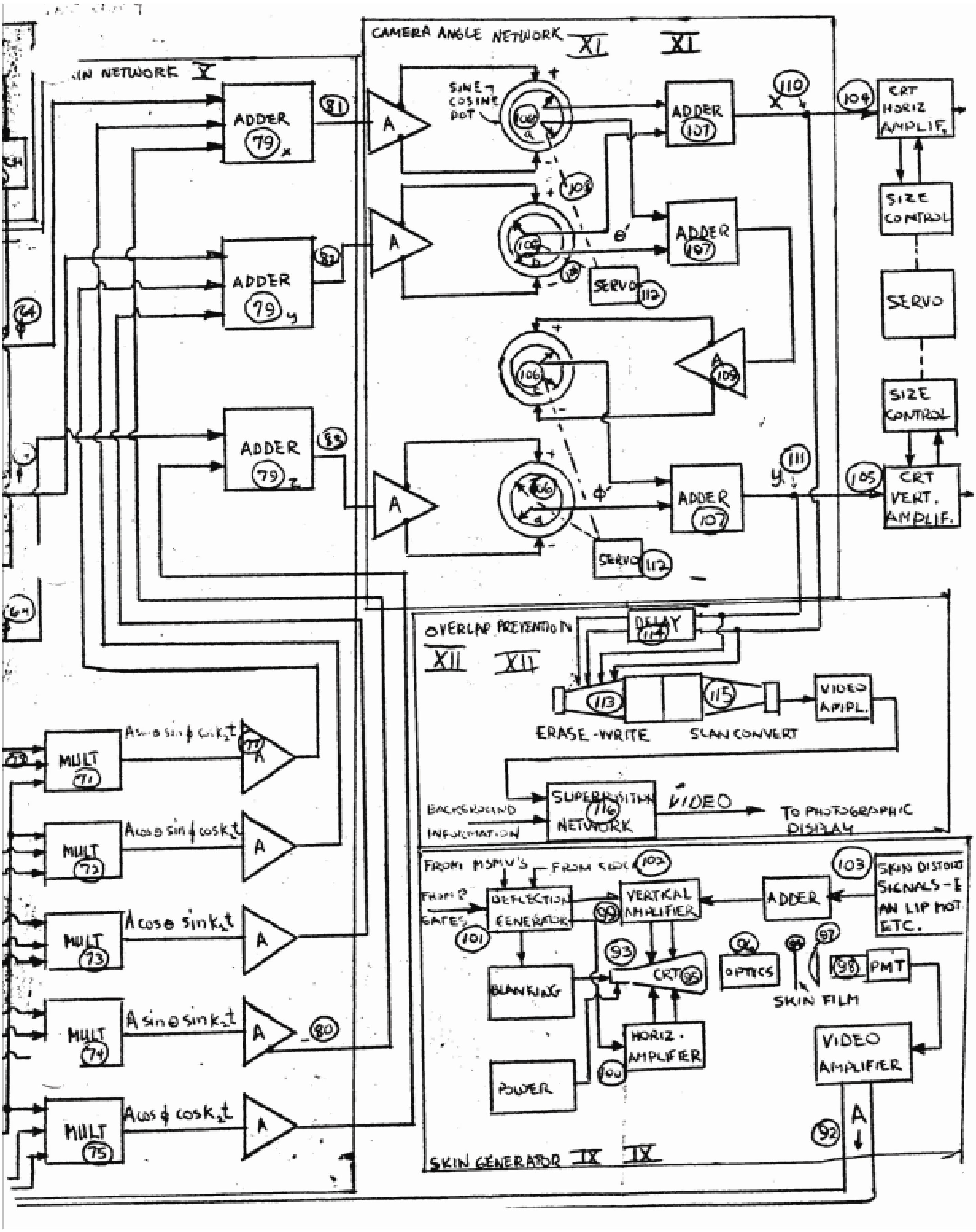
SAMPLER GATE
MSMV
FUNCTION GENERATORS
SKIN NETWORK IX


CAMERA ANGLE NETWORK XI XI
ADDER 79x
ADDER 79y
ADDER 79z
SINE-COSINE POT
ADDER 107
CRT HORIZ AMPLIF.
SIZE CONTROL
SERVO
CRT VERT. AMPLIF.
OVERLAP PREVENTION XII XII
DELAY 114
ERASE-WRITE
SCAN CONVERT
VIDEO AMPL.
BACKGROUND INFORMATION
SUPERPOSITION NETWORK
VIDEO
TO PHOTOGRAPHIC DISPLAY
MULT 71
MULT 72
MULT 73
MULT 74
MULT 75
DEFLECTION GENERATOR
VERTICAL AMPLIFIER
ADDER
BLANKING
CRT
OPTICS
SKIN FILM
PMT
HORIZ. AMPLIFIER
VIDEO AMPLIFIER
POWER
SKIN GENERATOR IX IX