

# TRANSMISSION OF RADIOMETER DATA FROM THE SYNCHRONOUS METEOROLOGICAL SATELLITE\*

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**Abstract** The Synchronous Meteorological Satellite uses a spin scanner radiometer which generates eight visual signals and two infrared signals. These signals are multiplexed and converted into a 28-Mbps data stream. This signal is transmitted to ground by quadriphase modulation at 1686.1 MHz. On the ground, the digital signal is reconstructed to an analog signal. To conserve bandwidth, an analog-to-digital converter with a nonlinear transfer function was used for the visual signals. The size of the quantization step was made proportional to the noise output of the scanner photomultiplier tube which increases as the square root of incident light. The radiometer data transmission link was simulated on a digital computer to determine the transfer function. Some results of the simulation are shown.

**Introduction** The Synchronous Meteorological Satellite<sup>1</sup> (SMS) employs a Visible Infrared Spin Scan Radiometer (VISSR). The VISSR provides eight visual and two infrared analog signals to a multiplexer unit. The multiplexer sequentially samples the ten signals and feeds the analog samples to a high-speed analog-to-digital converter. The visual signals are converted to six-bit words using a nonlinear A/D transfer function. The IR signals are converted to eight-bit words with a linear A/D converter. The composite signal is transmitted to ground by quadriphase modulation of a 1681.6-MHz carrier at a data rate of 28 Mbps. The ground equipment receives, demodulates, demultiplexes, and converts the digital data back to analog data.

**Selection of Digital Transmission Techniques** The requirements for the VISSR data transmission link are shown in Table 1. During the initial design phase of the SMS, a study was made to determine the most suitable technique for transmission of the VISSR data. FDM/FM, TDM/PAM/FM, and TDM/PCM/ QPSK were evaluated. The first two techniques are analog transmission techniques while the third is a digital transmission technique. The major factors which led to the selection of the TDM/PCM/QPSK technique were as follows:

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- a. High link margin
- b. High accuracy of data transmission
- c. No crosstalk between VISSR signal channels
- d. Relative immunity to amplitude and phase characteristics of RF transmission equipment caused by component drift
- e. Ability to accurately predict performance
- f. Availability of proven high-speed digital circuits and components
- g. Flexibility of growth to accommodate additional VISSR sensor signals.

Quadrphase modulation (QPSK) was chosen instead of PSK or PCM/FM to reduce RF bandwidth requirements.

**TABLE I**  
**REQUIREMENTS FOR VISSR DATA TRANSMISSION**

<u>Visual Signals</u>	
Number of Channels:	8
Bandwidth per Channel:	225 kHz
Low Frequency Response:	0.05 Hz
Linearity:	±1%
Dynamic Range:	54 dB
Maximum Required Peak-Peak Signal-to-rms Noise Ratio	39 dB
<u>IR Signals</u>	
Number of Channels:	2
Bandwidth per Channel:	26 kHz
Low Frequency Response:	0.02 Hz
Linearity:	±1%
Dynamic Range:	48 dB
Maximum Required Peak-Peak Signal-to-rms-Noise Ratio	54 dB
<u>RF Link</u>	
RF Bandwidth:	25 MHz
Carrier-to-Noise Density Ratio	90 dB-Hz

**System Description** Figure 1 shows a system block diagram of the VISSR data transmission system. The VISSR multiplexer accepts eight visual and two infrared signals and passes each signal through a presampling filter. The visual presampling filter is a five-pole linear phase filter with a 3-dB bandwidth of 225 kHz. The IR presampling filter is a five-pole linear phase filter with a 3-dB bandwidth of 26 kHz. Linear phase filters (similar to Bessel filters) were selected to improve the transient response of the system.

The visual data is sampled at a 500-kHz rate and the IR data is sampled at a 125-kHz rate. The basic 56-bit data frame format, shown in Figure 2, consists of one eight-bit sync or IR data word followed by eight six-bit visual data words. The first frame transmitted identifies the beginning of scan and the setting of the radiometer mirror. The bit rate is 28 Mbps\*\*. This data stream is differentially encoded into two 14-Mbps data streams which biphasic modulate two carriers at 81.6 MHz. These modulated carriers are added in phase quadrature and are upconverted to 1681.6 MHz. The signal is then amplified and transmitted to earth via the SMS electronic despun antenna.

Figure 2 also shows the transmission of the 2-ms preamble required to lock the ground demodulator carrier and clock tracking circuits prior to data transmission. Demodulator reacquisition is required once every rotation period of the satellite (600 ms) since VISSR data transmission occurs only during the time the VISSR is pointed toward Earth.

Figure 3 shows the functions of the SMS ground terminal for VISSR data reception. The QPSK demodulator reconstructs the carrier with a Costas loop. Separate coherent detection of the inphase and quadraturephase carriers are performed, followed by integrate-and-dump filters. Due to the high speeds, two integrate-and-dump filters are used for each carrier to allow a full bit period for discharging one filter while the other is integrating data. A quaternary differential decoder is used to combine the two data streams in one 28-Mbps data stream.

Bit synchronization is provided with additional integrate-and-dump filters which integrate across the bit transition to provide a dc error voltage for the bit sync VCO.

The data output from the QPSK demodulator is normally passed to a data stretcher which stores the data in buffer memory for retransmission via the SMS at a slower rate. To provide the capability to measure the VISSR data transmission link performance independently from the line stretcher, a test mode is provided where the 28-Mbps data is demultiplexed and fed into separate D/A converters. The results presented in this paper were obtained using this test mode. These results will be similar to those obtained with operational equipment except for differences in the interpolating circuits and smoothing filters used by individual users after digital-to-analog conversion.

**Analog-to-Digital Conversion** A linear A/D converter is used to convert the IR analog signal voltage samples to eight-bit digital words. This A/D converter generates an rms quantization noise which is 59 dB below the maximum peak-to-peak signal voltage from the IR detector and approximately 5 dB below the IR detector noise output. Thus, quantization noise degrades the IR link by 0.2 dB.

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\*\* A 14.0-Mbps bit rate is also available by ground command. In this mode, only four visual channels and two IR channels are transmitted.

A linear eight-bit A/D converter could also be used for the visual channel. However, the resultant transmission rate is 37.5 Mbps. To reduce the transmission bandwidth and increase link margin, a six-bit nonlinear A/D converter was adopted, leading to a total transmission rate of 28 Mbps. The transfer function used for the visual channels is shown in Figure 4. This function is matched to the noise characteristics of the photomultiplier detectors used in the VISSR. The output noise of the multiplier increases in proportion to the square root of the output signal. The transfer function of Figure 4 is composed of eight linear segments to provide an approximation to the square root function. As the analog-input voltage increases, the quantization noise also increases due to the increased size of the quantization interval. However, this quantization noise is always less than the noise from the VISSR, as illustrated in Figure 5. The combined camera-quantization noise is about 0.5 dB greater than camera noise alone.

The nonlinear A/D converter is implemented as shown in Figure 6. The output of the sample and hold is applied to an eight-level quantizer. The quantizer is made up of seven high-speed comparators with their thresholds set at nonlinear intervals. The outputs of the quantizer are decoded by logic to provide the three most significant bits of the PCM output word.

The output of the three-bit nonlinear A/D converter is converted to an analog voltage which is subtracted from the input voltage. The difference is then converted by a three-bit linear A/D converter to generate the three least significant bits of the PCM word. Parallel circuit techniques are used in both A/D converters to achieve the necessary conversion speed. A conversion is completed in approximately 130 ns, which leaves 84 ns for the sample and hold and the multiplexer.

The reference voltage which determines the accuracy of the A/D conversion is sampled periodically and transmitted to ground by the satellite PCM telemetry link.

**Computer Simulation** A computer simulation<sup>3</sup> of the visual channel transmission link was performed to assist in the specification of the presampling filter design, to predict performance of the total link, and to provide criteria for evaluation of test data. Figure 7 shows the functions performed by the simulation program. Input analog data, either sine waves or square waves, are generated by the computer in the form of 12-bit words at sample periods corresponding to onetenth the sampling period of the VISSR link. Similarly, the analog data at the A/D output is represented by 12-bit words at 10 times the link sampling rate. The presampling filter and smoothing filters were programmed using the Z-domain analysis.

The modulation transfer function (MTF) of the link was determined by applying an input waveform of the form

$$V_{in} = V_1 + V_2 \sin(2\pi ft)$$

Figure 8 shows the amplitude response for  $324 \text{ mV} \leq V_1 \leq 4853 \text{ mV}$  and  $V_2 = 259 \text{ mV}$ . (Full range is 0 to 5000 mV.) The figure shows a response change of 1 to 2 dB caused by the variation of  $V_1$ . This change is a result of the nonlinear A/D converter.

Figure 9 shows the phase and group delay for the same simulation. The results shown in both Figures 8 and 9 include the effects of aliasing distortion which are significant at frequencies above one-half the sampling (i.e., 250 kHz). The simulation shows a usable response up to about 225 kHz where the gain is down 11 dB. (225 kHz corresponds to a resolution of 0.5 nautical mile for a satellite spin of 100 rpm.)

The simulation has also been used to predict transient response to a step function as shown in Figure 10.<sup>4</sup> This simulation includes the VISSR and, thus, shows the system response to a step function of light at the radiometer input. The results show no overshoot and a rise time of approximately 3  $\mu\text{s}$ . This rise time corresponds to an angular rise time of 0.031 m $\Omega$ , equivalent to 0.6 n. mi. on the ground.

**Satellite Hardware Characteristics** The engineering model of the VISSR multiplexer and A/D converter built for SMS is shown in Figure 11. The flight unit is similar except extra cards are added to provide full redundancy. The basic building block is a card (Figure 12) using a multilayer printed circuit card to reduce size and weight.

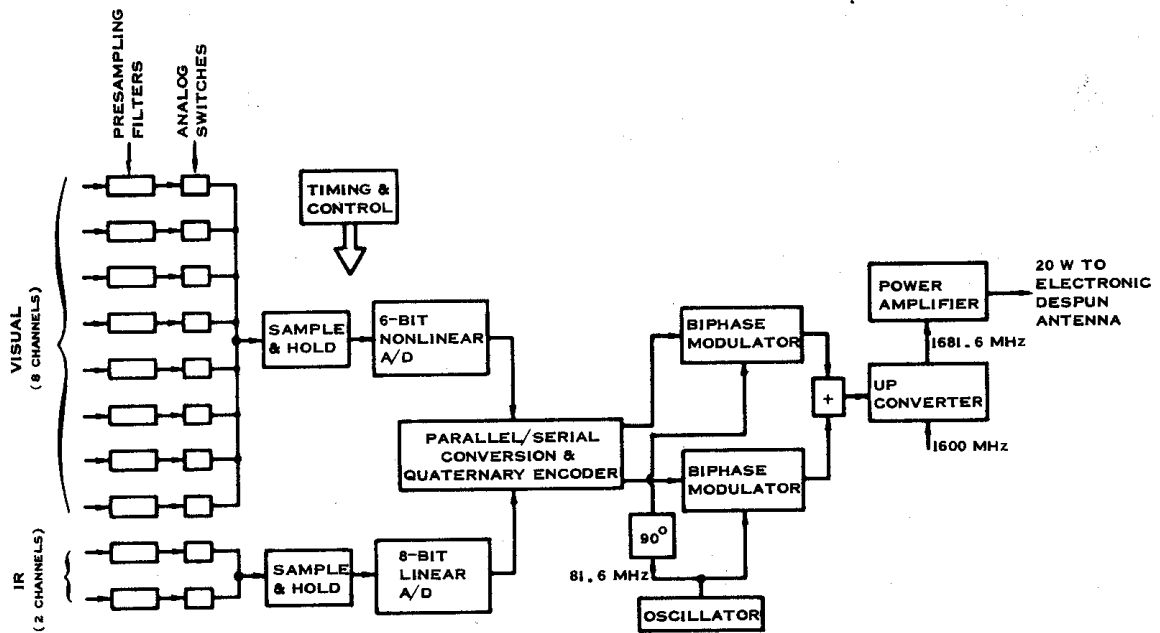
The complete unit measures 10 x 11 x 6 inches, weighs 14 pounds, and consumes 35 watts peak. Average power over the satellite spin period is about 3 watts since data is transmitted only when the VISSR is pointed toward Earth.

**Acknowledgements** The development of the SMS radiometer data transmission link was made possible by the efforts of many people at NASA/GSFC and Philco-Ford. In particular, the author wishes to acknowledge the work of K. C. Ward, L. Lamin, and W. K. S. Leong in performing the analysis and computer simulation work. B. Jackson, G. Morrow, and L. Kirby were responsible for the multiplexer/demultiplexer design, and P. Jones and L. Kjerulff were responsible for the QPSK modulator and demodulator design.

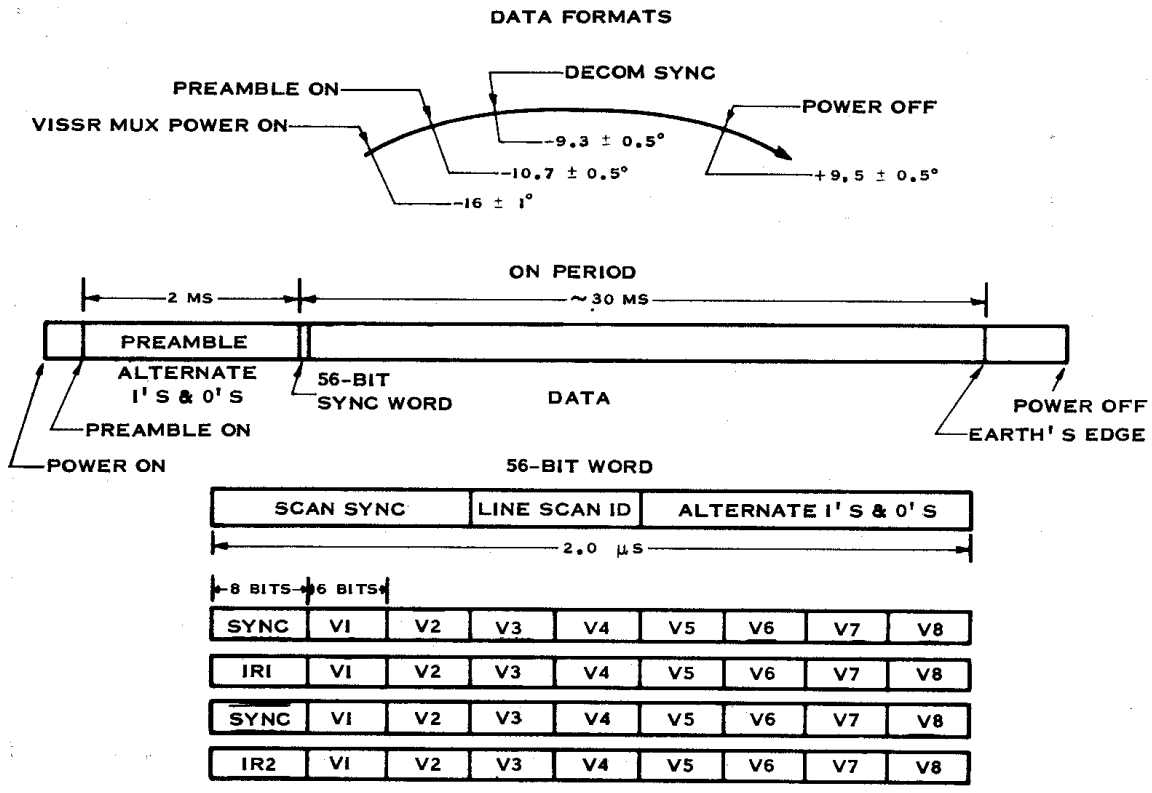
## References

1. P. T. Burr, F. B. Pipkin, "The Synchronous Meteorological Satellite (SMS) System," NTC Record 72-CHO, 601-5-NTC, National Telecommunications Conference, Houston; Dec. 4-6, 1972.

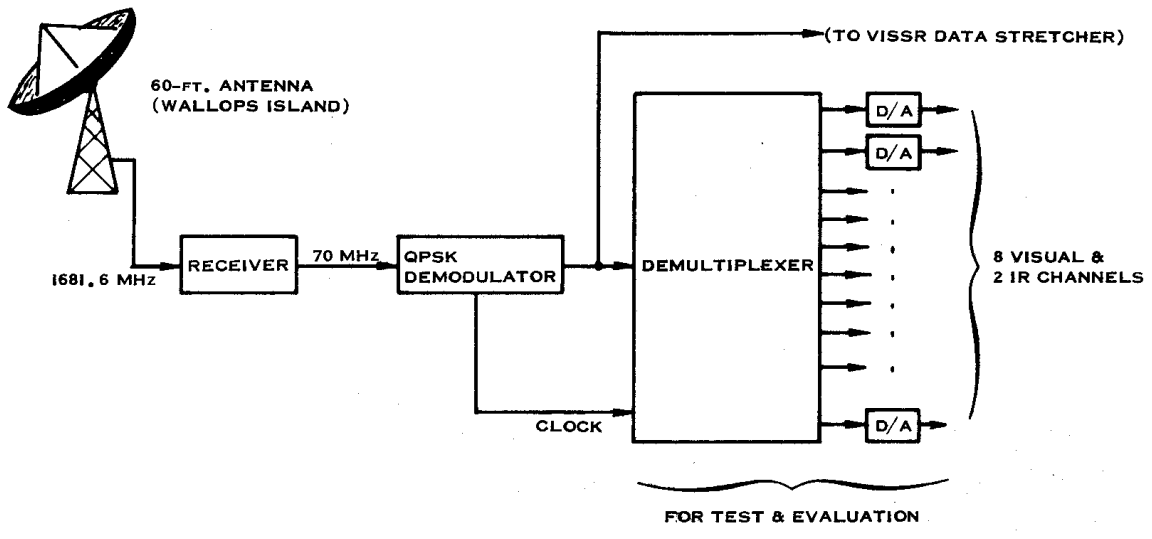
2. "Synchronous Meteorological Satellite," Phase C design Report, Philco-Ford WDL-TR4545; June 30, 1971.
3. L. Lamin, W. Leong, "VISSR Mux/Demux: Performance Simulation," Philco-Ford TM SMS-PCC-5154; October, 1972
4. L. Lamin, W. Leong, "VISSR Visual Channel Output Waveforms, Philco-Ford TM SMS-PCC-5749; April 6, 1973.



**Figure 1 Functional Block Diagram of VISSR Data Transmission Equipment in Satellite**



**Figure 2 Data Formats for VISSR Transmission**



**Figure 3 Functional Block Diagram of VISSR Data Receiving Equipment on Ground**

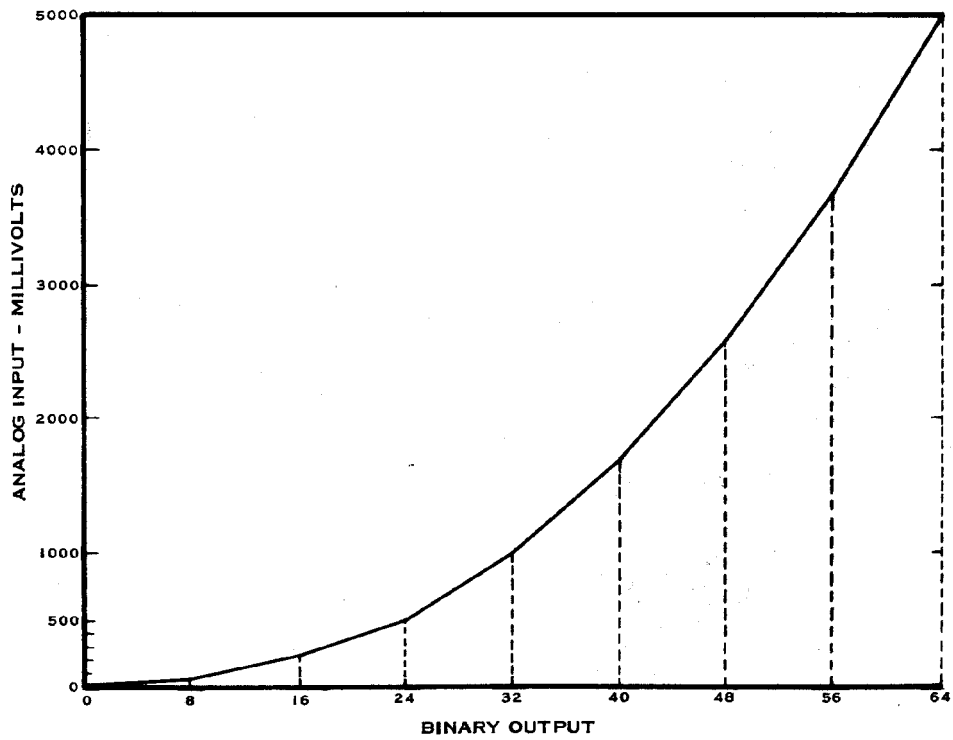


Figure 4 Transfer Function of Visual Channel A/D Converter

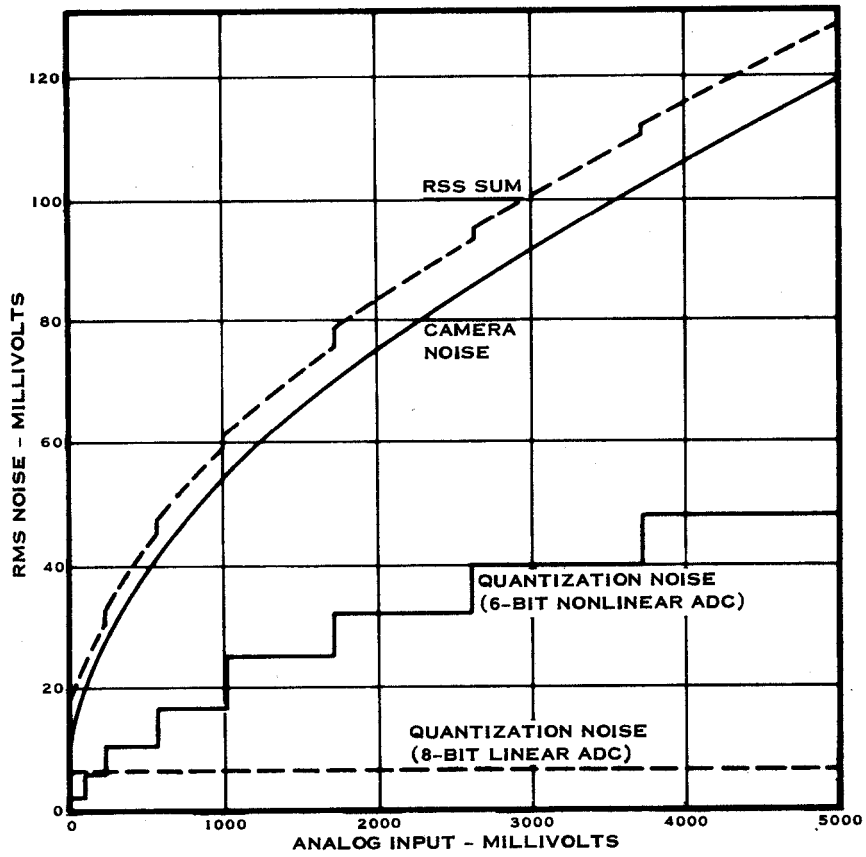
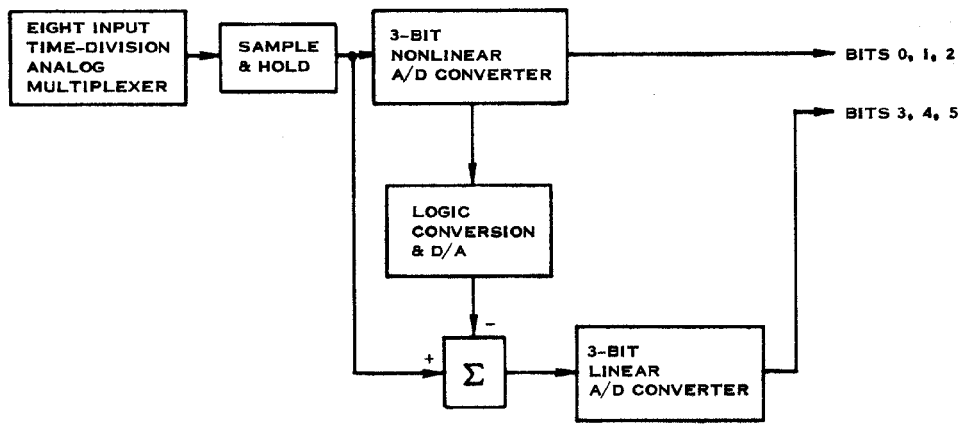
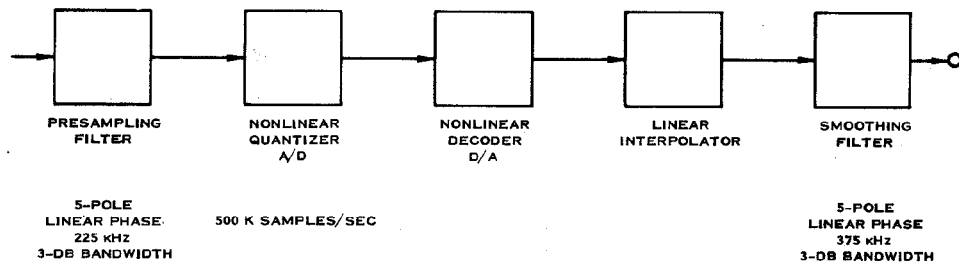


Figure 5 Noise in Visual Signal Link

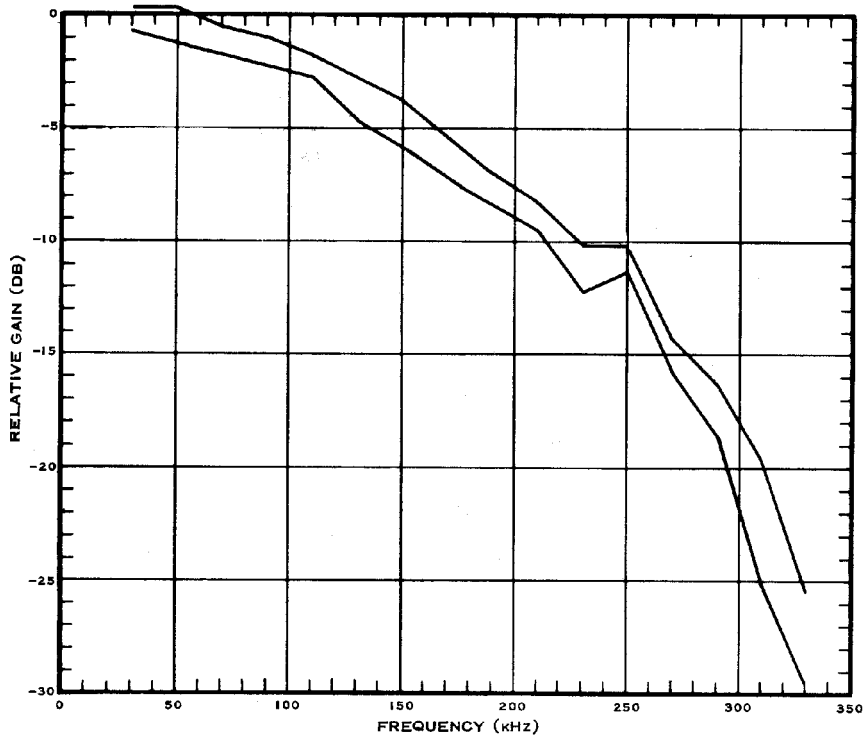




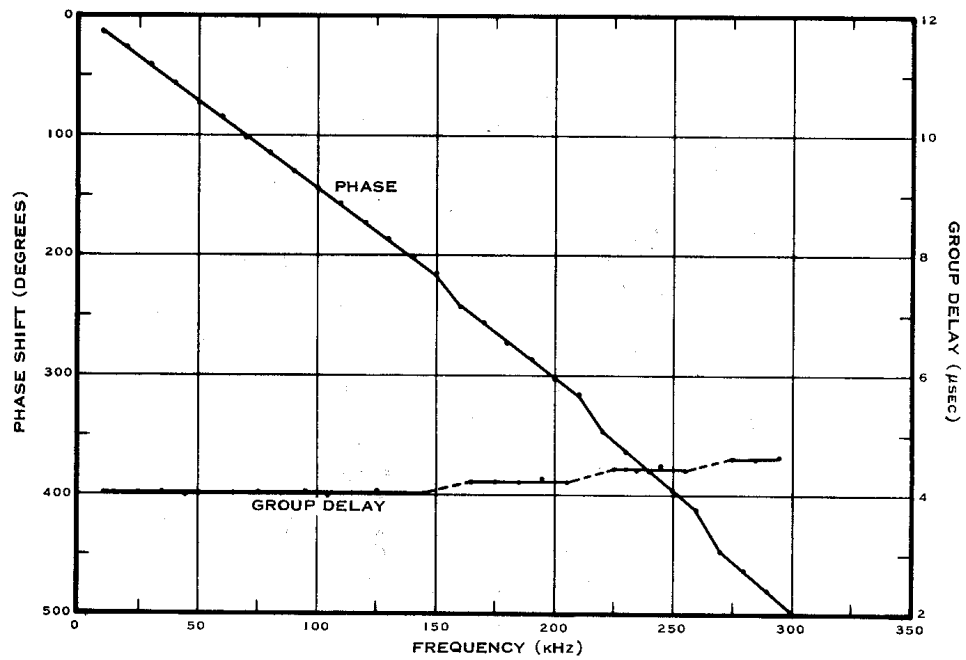
**Figure 6 6-Bit Nonlinear Analog/Digital Converter**



**Figure 7 VISSR Visual Transmission Link Simulation Block Diagram**

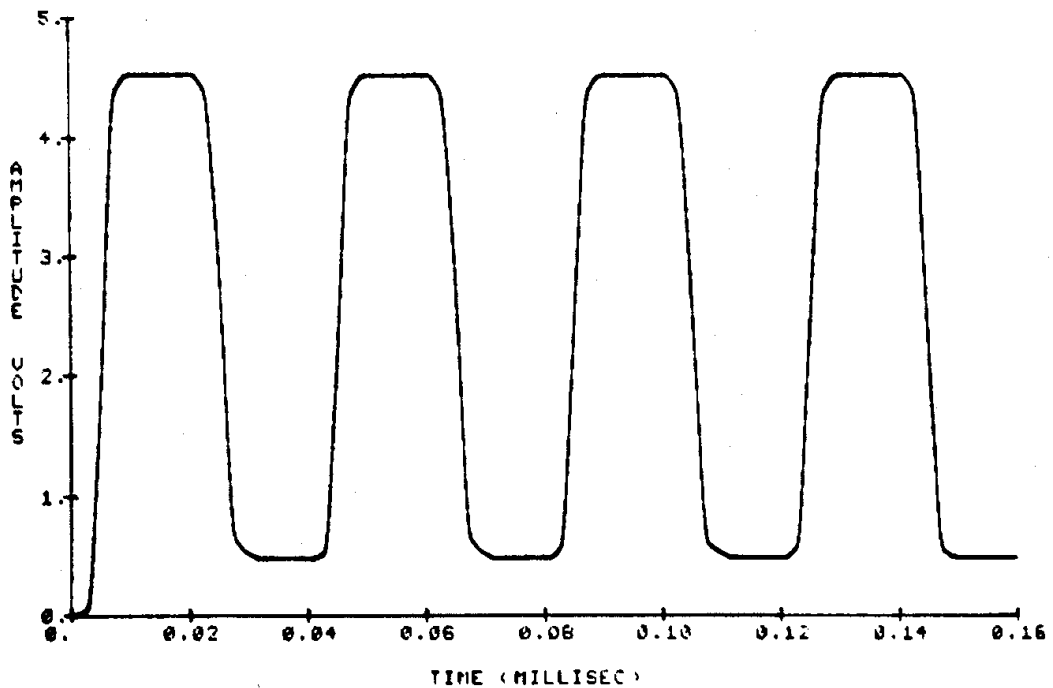


**Figure 8 Visual Channel Transmission Link Amplitude Response from Presampling Filter Input to Smoothing Filter Output**

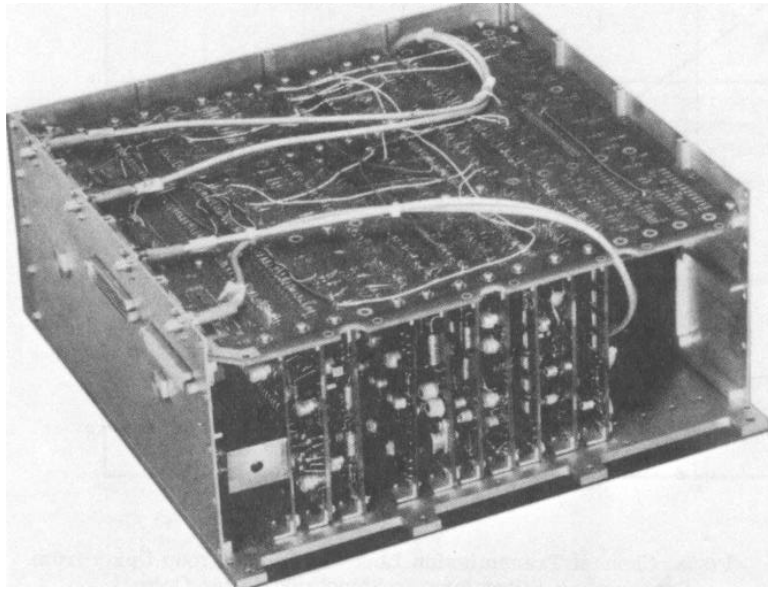


**Figure 9 Visual Channel Transmission Link Phase and Group Delay from Presampling Filter Input to Smoothing Filter Output**

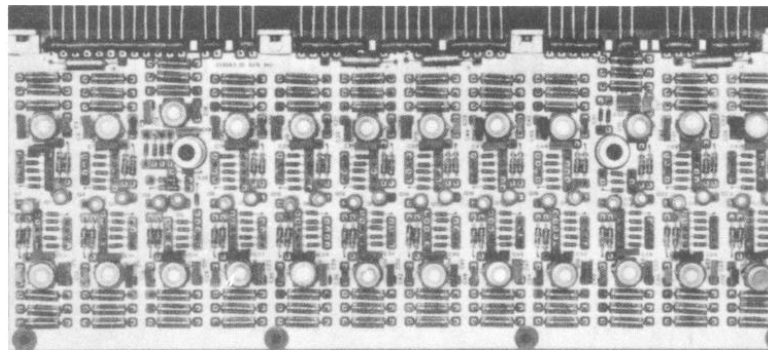
SIMULATED RESPONSE OF COMPLETE VISSR VISUAL CHANNEL 4/11/73  
 CAMERA PLUS MUX DEMUX AT OUTPUT OF CDA EQUIPMENT  
 INPUT OF CAMERA IS  $V1+U2*\text{SIGN}(\text{SIN}(2*\text{PI}*F*T))$  WHERE  
 $V1=2.500$  VOLTS,  $U2=2.000$  VOLTS,  $F= 25.000$  KHZ  
 SAMP. PHASE= 1. -3 DB BANDWIDTH OF PRESAMP FILTER=215 KHZ  
 WITHOUT CAMERA NOISE



**Figure 10 Response of VISSR Plus Visual Channel Transmission Link**



**Figure 1 VISSR Multiplexer and A/D Converter**



**Figure 12 VISSR Multiplexer and Layout View**