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Companding Flash Analog-To-Digital Converters

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COMPANDING FLASH ANALOG-TO-DIGITAL CONVERTERS

BY

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THESIS

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ABSTRACT

This report will demonstrate how a companding flash analog-to-digital converter can be used to satisfy both the dynamic range and resolution requirements of an infrared imaging system. In the past, infrared imaging systems had to rely on analog electronics to process a thermal image. This was costly and, in many ways, inefficient but the only way to perform the function. Digital processing was impractical because ADC conversion speeds were slow with respect to video frequencies. Furthermore, it is impossible to gain the necessary dynamic range using linear conversion techniques without large digital wordlengths. Therefore, the principles of companding flash analog-to-digital converters will be shown and analyzed. The advantages of companding with respect to linear conversion will be demonstrated and the problem of sufficient comparator resolution within the compression region outlined.

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CHAPTER I

INTRODUCTION

Radiant Energy

Radiant energy has a dual nature and obeys laws that may be explained in terms of a stream of packets of energy called photons, or in terms of transverse electro-magnetic waves. The concept of photons is used to explain the interactions of radiation and matter that result in a change in the form of energy present. The concept of transverse electro-magnetic waves is used to explain the propagation of radiant energy through various substances and, in some of the phenomena, of image formation.

One concept of radiant energy is that of a simple transverse electro-magnetic wave. A transverse wave can be described by points that oscillate in the same plane back and forth across an axis perpendicular to the direction of propagation. All radiant energy, regardless of the frequency of oscillation, obey the laws of wave motion including reflection, refraction, interference, and diffraction. In a vacuum, the velocity of propagation is the same for all frequencies. It is given by 3.00×10^8 meters/sec. In matter, this velocity is less and a function of frequency of oscillation.

Physicists have known since the early 19th century that light is propagated as a transverse wave, but originally they thought that the wave was mechanical in nature, requiring some medium for its propogation. Experiments demonstrated that light could travel through the best laboratory vacuum; the medium for its propagation was postulated as an extremely diffuse substance, called ether, present even in a vacuum. Maxwell proved that light was an electro-magnetic oscillation with the publication of his four laws of electro-magnetism [1].

Electro-Magnetic Spectrum

The electro-magnetic spectrum is continuous from long waves with frequencies approaching zero to cosmic rays with frequencies approaching infinity. The properties of electro-magnetic waves depend on their frequency, which is important in determining heating effect, visibility, penetration, etc. Frequency bands have been chosen which group these properties, and each has its usefulness. Figure 1 shows the electro-magnetic spectrum and frequency bands. Visible light is used to see one's surroundings and is the most intrinsically obvious of frequency bands. Radio and microwaves are used in communicating information, x-rays are used in medical diagnosis, etc.

At the beginning of the 20th century, it was found that the wave theory would not account for all the properties of radiation. In 1900 the German physicist, Max Plank, demonstrated that the emission and absorption of radiation occurs in finite packages of energy, which he called quanta. Phenomena involving the interaction between radiation and matter can only be explained by the Quantum Theory. Quantum characteristics are particularly apparent in the

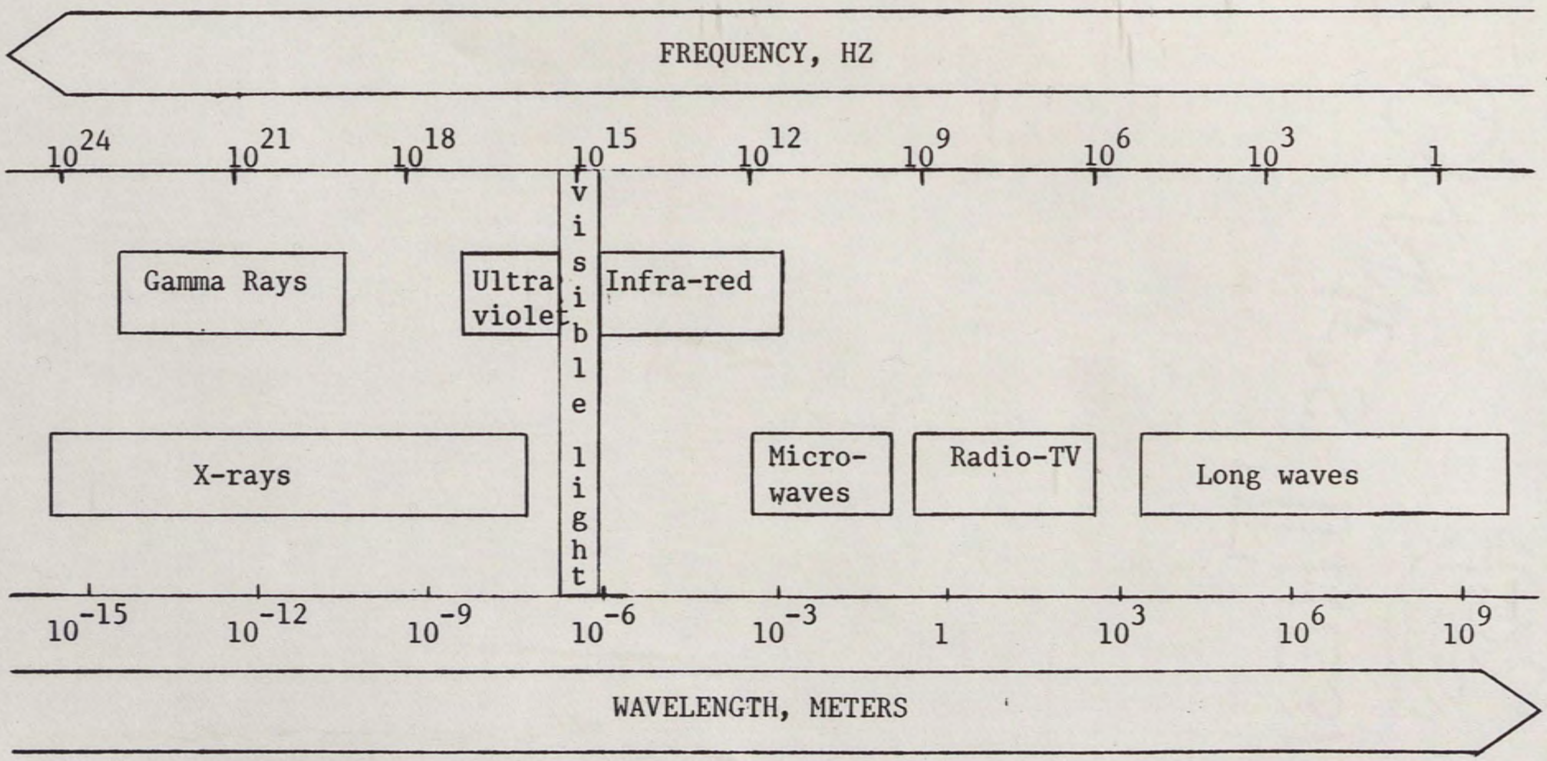

Figure 1. The Electro-Magnetic Spectrum.

high frequency bands of the electro-magnetic spectrum. Physicists recognize that electro-magnetic radiation has both wave and quantum properties [1,2].

Thermal Imaging

Thermal imagery makes use of the fact that every body emits electro-magnetic radiation with a wavelength distribution characteristic of its absolute temperature and surface emissivity. Emissivity is defined as the relative ability of a surface to radiate energy as compared with that of an ideally black surface under the same conditions. Variations in the temperature over the surface of a body will, provided the emissivity is constant, form what is called a thermal image, by analog with the optical image formed by reflected visible radiation [3].

The temperature of terrestrial bodies can range from approximately 0K to over 6000K. Ambient is the average temperature of the surroundings and is approximately 300K. A typical military infrared detection system must be able to see both the horizon and a flaming jet exhaust. See Figure 2 for a plot of a typical infrared scan.

A thermal image is made visible by scanning the body and measuring the intensity of radiation from each point. This information is then used to produce an optical image which reproduces the thermal intensity pattern. Such a thermal imaging system exploits most aspects of infrared technology involving sophisticated imagery, detection, signal processing, and display techniques [3].

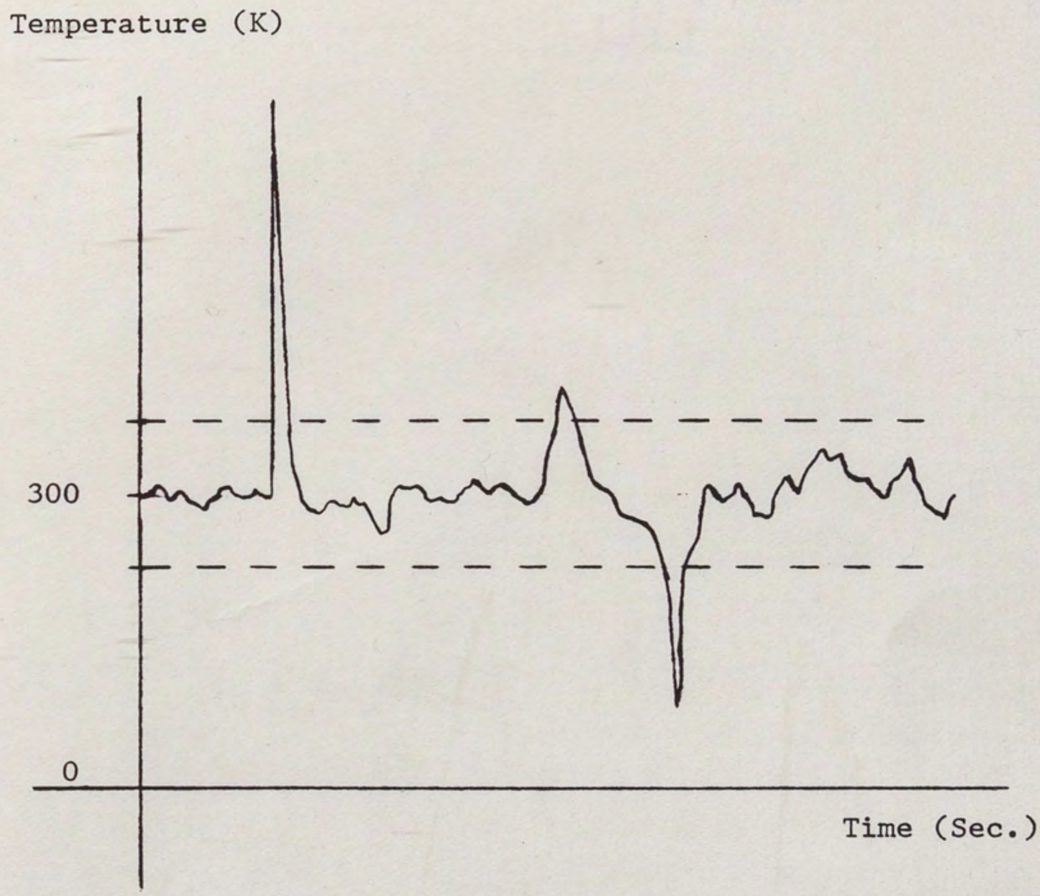

Figure 2. Typical Terrestial Infrared Scan.

A typical infrared imaging system would contain:

(1) Optics

(2) Infrared detectors

(3) Interface

(4) Signal Processing Electronics

(5) CRT display

The optics of an infrared imaging system contain a complex configuration of lenses and reflectors which concentrate and focus infrared radiation onto a detector array. Simple glass refractory components will serve for only a limited range in the infrared, as radiation over 3 u-meters is heavily absorbed. There are three phenomena which will prevent a given material from being used successfully to make a lens or window for an infrared system.

(1) Reflectivity may be so great that only a small fraction of the radiant power enters the lens. The reflection at an abrupt interface between two media depends on the refractive indices J_1 and J_2. The reflective index of air is approximately one while that of semiconductors is, in general, four. The expression for reflectivity is given by:

$$\text{Reflectivity} = \frac{(1 - J_1/J_2)^2}{(1 + (J_1/J_2)^{2})} \qquad (1.1)$$

For the air/semiconductor interface the reflectivity is about one-third. Without remedy, this would make any semiconductor lens very lossy since, even without subsequent loss by absorption, only two-thirds of the incident radiation would pass through. The solution to this problem is to apply thin coatings of materials with intermediate indices to the lens.

(2) A loss mechanism involving the cyclic movement of charged particles in the materials caused by the alternating electric field of the radiation.

(3) A loss mechanism involving the liberation of charged particles by the absorption of photons.

The problems encountered in making suitable lenses for use in the infrared can be avoided if it is possible to use reflecting elements for imaging and focusing. The permissible surface irregularity in a reflector is proportional to the wavelength of the radiation in use; therefore, the tolerances on an infrared mirror will be more lax than that on an optical mirror. Infrared reflectors are usually made by the deposition of a thin metalic film on a suitably shaped substrate, and provided that its geometry is stable, the substrate material is not important [2,3].

A semiconductor infrared detector senses radiation by the fact that a photon striking its surface mobilizes an electron in the crystal lattice. Electrons in a semiconductor are allowed to assume energies which lie in certain well-defined bands. The two highest, the conduction band and valence band, are the operating regions in photo-detection. Between these bands is an energy gap which must be surmounted in order to bring an electron from the stable valence band to the mobile conduction band at a given temperature. The electrons in the conduction band are there from either photon excitation or thermal excitation. For a photodetector to be useful, the thermally excited electrons must be minimized to optimize the signal-to-noise ratio. This is done by refrigerating the detector in a device called a Dewar. The significant characteristics of a photodetector are the wavelength region to which it responds, the speed of response, and the magnitude of the signal it provides [3].

The band gap of a semiconductor material determines the frequency of radiation to which it will respond. Elemental Silicon and Germanium have band gaps of 1.1 and .7 electron volts respectively, which puts their long wave responses at 1.24 and 1.8 micrometers. This however is only brushing the extreme end of the infrared spectrum, and to reach further it is necessary to use semiconductor compounds of two or even three elements. Refer to Table 1 for a list of common semiconductor alloys [3].

TABLE 1. SEMICONDUCTOR ALLOYS AND RESPONSE CHARACTERISTICS

MATERIAL	TEMPERATURE (°K)	APPROXIMATE CUT-OFF WAVELENGTH (MICROMETERS)
Ge	300	1.8
Si	300	1.2
Ge + Cu impurity	18	30.0
Ge + Au impurity	35	15.0
InAs	77	3.0
InSb	77	5.5
Cd-HgTe	77	13.0
Pb-SnTe	12	14.0

An infrared interface must transfer signals between detector/ Dewar and signal processing electronics while minimizing additive noise. There are any number of techniques which can be used but the trend is towards parallel digital data or fiber-optic links. The problem with parallel digital data is that no linear ADC carries enough bits to provide for the required resolution/dynamic range while having adequate conversion speeds for infrared/video signal formats.

Signal processing electronics control the painting of an image on to a CRT. Commercial television uses a 525 line by 420 column format refreshed 30 times per second. Military systems usually require greater definition necessitating a larger number of rows and columns. To enhance the capabilities of an infrared system, all signal processing functions can be performed digitally. This increases reliability, dependability, and uniformity. Once a digital system is designed, it is very easy to produce copies which perform exactly the same function. Digital systems are not subject to component aging, therefore reducing the problem of calibration. Digital systems are also immune to much of the electronic noise inherent in any operational environment.

Digital processing adds computational power to a system and, therefore, image enhancement capabilities. Image enhancement is the processing of images to increase their usefulness. When images are enhanced for human viewers, the objective may be to improve perceptual aspects such as image quality, intelligibility, or visual appearance.

Some methods of image enhancement are: modification of contrast or dynamic range; edge enhancement; reduction of additive, multiplicative, and salt-and-pepper noise; reduction of blurring; and display of non-image data [4,5].

To implement digital signal processing, a signal must be converted from an analog to a digital quantity. This function is performed by a device called an Analog-to-Digital Converter (ADC).

CHAPTER 2

ANALOG-TO-DIGITAL CONVERTER (ADC)

Analog-to-Digital Conversion

An ADC is a device with a continuous analog input signal and digital output. The digital output is the nearest approximation to the analog value at some instant in time. This is due to the fact that digital signals are both discrete and quantized. If a digital number contains N bits, then it can assume 2^N values. The equations describing the operation of an ADC are:

$$A = R\left[\frac{b_1}{2} + \frac{b_2}{4} + \frac{b_3}{8} + \dots + \frac{b_N}{2^N} + \frac{b_{N+1}}{2^{N+1}} + \dots\right] \qquad (2.1)$$

$$\bar{A} = R\left[\frac{b_1}{2} + \frac{b_2}{4} + \frac{b_3}{8} + \dots + \frac{b_N}{2^N}\right] \qquad (2.2)$$

$$QE = R\left[\frac{b_{N+1}}{2^{N+1}} + \frac{b_{N+2}}{2^{N+2}} + \dots\right] \qquad (2.3)$$

$$A = \bar{A} + QE \qquad (2.4)$$

where

A = an analog value of some instant of time,

$\bar{A}$ = the digital approximation of A,

QE = quantanization error,

R = reference voltage equal to maximum value of A,

b_n = the nth digit of a binary word,

N = the total number of digits in a digital word.

The larger the value N, the better the approximation of $\bar{A}$ to A. The problem with carrying more digital bits is that it yields a more complex hardware design and greater costs. There is a cost function which must be optimized to determine the proper mix of cost and design complexity [6].

Output Codes

The numbering system mentioned above is called unipolar; that is, the analog value A is allowed to range from zero to a positive reference R. Other numbering systems allowing the analog value A to range over positive and negative values exist, and are called bi-polar output codes. ADCs which implement bi-polar codes are much more complex with respect to hardware than those which implement unipolar codes [6].

ADC Errors

There are a number of errors introduced into an analog-to-digital conversion. The most obvious error is due to the quantanization of an analog signal. This is sometimes described as resolution or precision of conversion and is a function of the number of bits carried by the digital word. The number of bits determines how many values, from zero to full scale, are available for representing an analog quantity in the digital domain. The maximum quantanization error is $\pm$ 1/2 LSB.

Electronic equipment error is the sum of the errors contributed by the circuitry through which the analog signal has to pass before and during conversion. This class of errors can be further divided into random and systematic errors.

Random errors are due to the statistical distribution of component values. Random errors follow a Gaussian distribution; thus their total contributed expected error, e_r, is

$$e_r = \sqrt{\sum e_i^2} \qquad (2.5)$$

where e_i are the individual error components.

Systematic errors can sometimes be eliminated through careful adjustments. Others, such as temperature dependent errors, and the finite value of power supply regulation, have to be added linearly for the worst-case condition, that is, over the total temperature range that the ADC is specified to operate, and over the maximum power supply variations [6].

Flash ADC

Flash ADCs use one analog comparator, with a fixed voltage Vref at one of its inputs, for every quantanization level in the digital word from zero to full scale. A common reference voltage and a precision resistor chain apply the Vref bias to each comparator that differs by one LSB. The input analog voltage is connected to the other input of each comparator so that an analog comparison can be made with all the reference voltage levels representing all the quantanization levels. The outputs of these comparators drive encoding logic to generate the equivalent digital word. The value of the output digital word is dependent upon the comparators, which have detected the input analog voltage which is greater than their reference voltage. The conversion process is extremely fast because the conversion is completed in one operation and is asynchronous; its speed is determined by the sum of the propogation delays of a comparator and of the encoding logic. The major disadvantage to the flash ADC is that for each additional binary bit in the digital word, the number of comparators and encoding circuitry is doubled [6].

CHAPTER 3

COMPANDING

Companding is a means of increasing the dynamic range of a system. Compandors have been used to increase the dynamic range of electronic communications systems in radio and, for over fifteen years, in the telephone system. In addition, companding has been used in audio frequency ADCs. Until recently, it appears to have found little use in video but with the advent of digital television and the increased importance of thermal imaging systems, the use of video frequency compandors is expected to increase.

Companding is a compound word for compression and expansion which describes the signal processing nonlinear functions that are performed. This processing is a trade-off between resolution and dynamic range. There are many possible companding techniques, but they all must satisfy the requirement that, as a system, the compression/expansion function be a linear operation. Its purpose is to enhance the quality of quantanization for small signal values compared to that obtainable by uniform quantanization. Two companding schemes which are in widespread use today in the telephone switching system are the Mu-law and the A-law. The Mu-law has been implemented with the American telephone switching system while the A-law has been used by the European telephone system.

The Mu-laws defining equation for compression and expansion are:

Compression

$$V_c = \frac{a \log(1 + uV_i/a)}{\log(1 + u)} \quad \text{for } 0 \leq V_i \leq a \qquad (3.1)$$

Expansion

$$V_o = (a/u)[\exp((V_c/a) \log(1 + u)) - 1] \quad \text{for } 0 \leq V_c \leq a \qquad (3.2)$$

where

V_i = input voltage signal

V_o = compressed voltage signal

a = reference voltage

u = compression parameter

V_o = output voltage signal

Similar equations can be written for negative values of V_i.

The A-law defining compression equations are:

$$V_c = \frac{AV_i}{1 + \log A} \quad \text{for } 0 \leq V_i \leq \frac{1}{A} \qquad (3.3)$$

$$V_c = \frac{1 + \log(AV_i)}{1 + \log A} \quad \text{for } \frac{1}{A} \leq V_i \leq 1 \qquad (3.4)$$

while for expansion

$$V_o = \frac{(1 + \log A)V_c}{A} \qquad \text{for } 0 \leq V_c \leq \frac{1}{1 + \log A} \qquad (3.5)$$

$$V_o = (1/A)[\exp((1 + \log A)V_c - 1)] \qquad \text{for } \frac{1}{1 + \log A} \leq V_c \leq 1 \qquad (3.6)$$

Companding curves such as the Mu and A laws are continuous functions which are almost impossible to implement in reality. A smooth curve would require an infinite number of quantanization steps of infinitesimal smallness. The cost of implementing a non-uniform quantanization system may be reduced considerably by limiting the number of quantanization steps specified. The quantanization levels are grouped into regions of constant step size. Each of these regions is referred to as a segment. The purpose of segmentation is to combine the advantages of compression with reasonable cost by approximating the smooth companding curves as a series of chords representing regions of uniform quantanization [7].

CHAPTER 4

COMPANDING FLASH ADC DESIGN

Segmented Companding Curve Design

The design chosen was picked for its simplicity since the principle of companding using a flash ADC is to be demonstrated with the specific application to infrared systems in mind. A three chord compression scheme such as that in Figure 3 is to be designed. The midrange chord is set so that its midpoint would correspond to the voltage produced by the ambient temperature. Ambient was chosen for symmetry and simplicity as half of full-scale voltage. The width of this chord can be chosen using two criteria.

(1) Signal swing about ambient to be compressed.

(2) Linear bit resolution required.

The outside chords are not critical as long as they retain enough quantanization levels to satisfy the given application. Half full-scale voltage was chosen as ambient because it makes the voltage per quantum the same for both outside chords. Each chord contains 32 quantanization levels; therefore, each of the outside chords has the same input voltage width. In reality, ambient would not correspond to half the full-scale voltage but would be skewed towards the lower end of the voltage scale. Each chord would then have an input voltage width which is different from the other two.

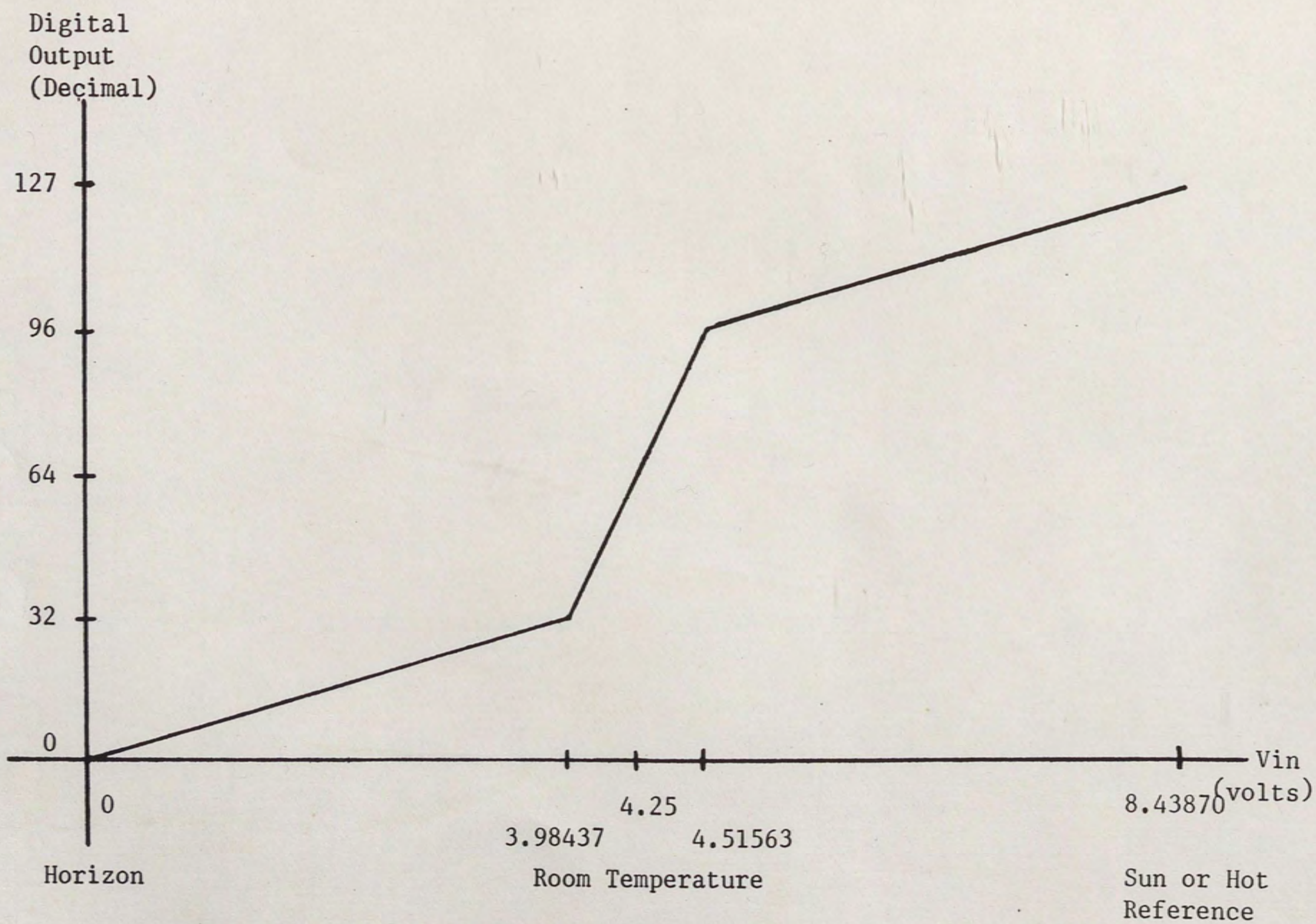

Figure 3. Designed 7-bit Companding ADC Diagram.

To find the resolution remaining in the non-compressed regions:

$$\frac{3.98437 \text{ volts}}{32 \quad \text{quantum}} = .124512 \text{ volts/quantum} \tag{4.3}$$

$$\frac{8.5 \text{ volts}}{2^N \text{ quantum}} = .124512 \text{ volts/quantum} \tag{4.4}$$

$$N = \log_2 68.2665 = 6.093 \tag{4.5}$$

This design obtains 10-bit resolution within the compression chord while still retaining better than 6-bit resolution in the other chords.

The potentiometers are configured as an adjustable resistor ladder. They provide voltage taps to set the voltages of Table 2. The defining equation for their adjustment is developed using voltage division and is simplified by the symmetry of the segmented companding curve of Figure 3.

$$\frac{R4}{R3 + R4} = \frac{3.98437}{4.25} \tag{4.6}$$

If R4 is arbitrarily chosen as 1 Kohms, then R3 is found to be 66.7 ohms. Symmetry would have R1 = R4 and R2 = R3, therefore

R1 = R4 = 1 Kohms

R2 = R3 = 66.7 ohms

This design was chosen to obtain 10-bit resolution within the compression chord.

Given: Vref+ = 8.5 volts

Vref- = 0.0 volts

N = 10 bits

$$\frac{\text{Vref+} - \text{Vref-}}{2^N} = .0083 \text{ volts/quantum} \quad (4.1)$$

The RCA CA3300 chip design necessitates using the 64 comparators between pin 10 of both chips as the compression region, therefore

$$.0083 \text{ volts/quantum} \times 32 \text{ quantum} = .26563 \text{ volts} \quad (4.2)$$

chip 1, pin 16 - 4.25 volts + .26563 volts = 4.51563 volts

chip 2, pin 16 - 4.25 volts - .26563 volts = 3.98437 volts [8].

TABLE 2. PINS AND APPLIED VOLTAGES

CHIP #	PIN NAME	PIN #	DESIGN VOLTAGE (VOLTS)
1	R+	9	8.5
1	RC	16	4.51563
1	R-	10	4.25
2	R+	9	4.25
2	RC	16	3.98437
2	R-	10	0.0

TABLE 3. MINIMUM INPUT VOLTAGE AND OUTPUT CODES

NUMBER	DIGITAL CODE	MINIMUM VOLTAGE (VOLTS)
0	0000000	0.00000
1	0000001	0.06130
2	0000010	0.18785
3	0000011	0.31440
4	0000100	0.44095
5	0000101	0.56750
6	0000110	0.69405
7	0000111	0.82060
8	0001000	0.94715
9	0001001	1.07371
10	0001010	1.20026
11	0001011	1.32681
12	0001100	1.45336
13	0001101	1.57991
14	0001110	1.70646
15	0001111	1.83301
16	0010000	1.95956
17	0010001	2.08611
18	0010010	2.21266
19	0010011	2.33921
20	0010100	2.46576
21	0010101	2.59231
22	0010110	2.71886
23	0010111	2.84541
24	0011000	2.97196
25	0011001	3.09852
26	0011010	3.22507
27	0011011	3.35162
28	0011100	3.47817
29	0011101	3.60472
30	0011110	3.73127
31	0011111	3.85782
32	0100000	3.98437
33	0100001	3.99267
34	0100010	4.00097
35	0100011	4.00927
36	0100100	4.01757
37	0100101	4.02587
38	0100110	4.03418
39	0100111	4.04248
40	0101000	4.05078
41	0101001	4.05078
42	0101010	4.06738
43	0101011	4.07568

TABLE 3 (Continued)

NUMBER	DIGITAL CODE	MINIMUM VOLTAGE (VOLTS)
44	0101100	4.08398
45	0101101	4.09228
46	0101110	4.10058
47	0101111	4.10888
48	0110000	4.11718
49	0110001	4.12549
50	0110010	4.13379
51	0110011	4.14209
52	0110100	4.15039
53	0110101	4.15869
54	0110110	4.16699
55	0110111	4.17529
56	0111000	4.18359
57	0111001	4.19189
58	0111010	4.20019
59	0111011	4.20850
60	0111100	4.21680
61	0111101	4.22510
62	0111110	4.23340
63	0111111	4.24170
64	1000000	4.25000
65	1000001	4.25830
66	1000010	4.26660
67	1000011	4.27490
68	1000100	4.28320
69	1000101	4.29150
70	1000110	4.29981
71	1000111	4.30811
72	1001000	4.31641
73	1001001	4.32471
74	1001010	4.33301
75	1001011	4.34131
76	1001100	4.34961
77	1001101	4.35791
78	1001110	4.36621
79	1001111	4.37451
80	1010000	4.38281
81	1010001	4.39112
82	1010010	4.39942
83	1010011	4.40772
84	1010100	4.41602
85	1010101	4.42432
86	1010110	4.43262

TABLE 3 (Continued)

NUMBER	DIGITAL CODE	MINIMUM VOLTAGE (VOLTS)
87	1010111	4.44092
88	1011000	4.44921
89	1011001	4.45752
90	1011010	4.46582
91	1011011	4.47413
92	1011100	4.48243
93	1011101	4.49073
94	1011110	4.49903
95	1011111	4.50733
96	1100000	4.51563
97	1100001	4.64218
98	1100010	4.76873
99	1100011	4.89528
100	1100100	5.02183
101	1100101	5.14838
102	1100110	5.27493
103	1100111	5.40148
104	1101000	5.52803
105	1101001	5.65459
106	1101010	5.78114
107	1101011	5.90769
108	1101100	6.03424
109	1101101	6.16079
110	1101110	6.28734
111	1101111	6.41389
112	1110000	6.54044
113	1110001	6.66699
114	1110010	6.79354
115	1110011	6.92009
116	1110100	7.04664
117	1110101	7.17319
118	1110110	7.29974
119	1110111	7.42629
120	1111000	7.55285
121	1111001	7.67940
la2	1111010	7.80595
123	1111011	7.93250
124	1111100	8.05905
125	1111101	8.18560
126	1111110	8.31215
127	1111111	8.43870

Circuit Description

A design for a 7-bit companding flash ADC using two RCA CA3300 chips is shown in Figures 4a and 4b. The internal layout of an RCA CA3300 is illustrated in Figure 5. The resistor ladder on these chips is biased by the circuit shown in Figure 4a to set the compression voltages. Digital output codes are displayed using eight LEDs. Seven of these LEDs are connected between chip outputs and ground. They are directly driven by the ADC outputs. The MSB is the overflow output of the chip containing the lower 64 comparators. When overflow goes high, it disables the output of that chip and enables the output of the other chip. When the LED is connected to this output it does not allow the voltage to go to its proper logic high state. This requires the insertion of a voltage follower to enable/disable the chip while properly driving the output LED [8].

The resistor ladder bias circuit is shown in Figure 4a and consists of 4 potentiometers, 3 operational amplifiers configured as voltage followers, and two 1 Kohm resistors. Potentiometers were chosen instead of precision resistors because their resistance can be changed and the design adjusted until an optium is found. Precision resistors would be used with a finalized design in production. The voltage followers serve to fix the ADC taps at whatever voltages are present on the bias resistor network and eliminate any paralleling of resistances. The 1 Kohm resistors between op amp outputs serve as a path for current removed from the flash ADC's

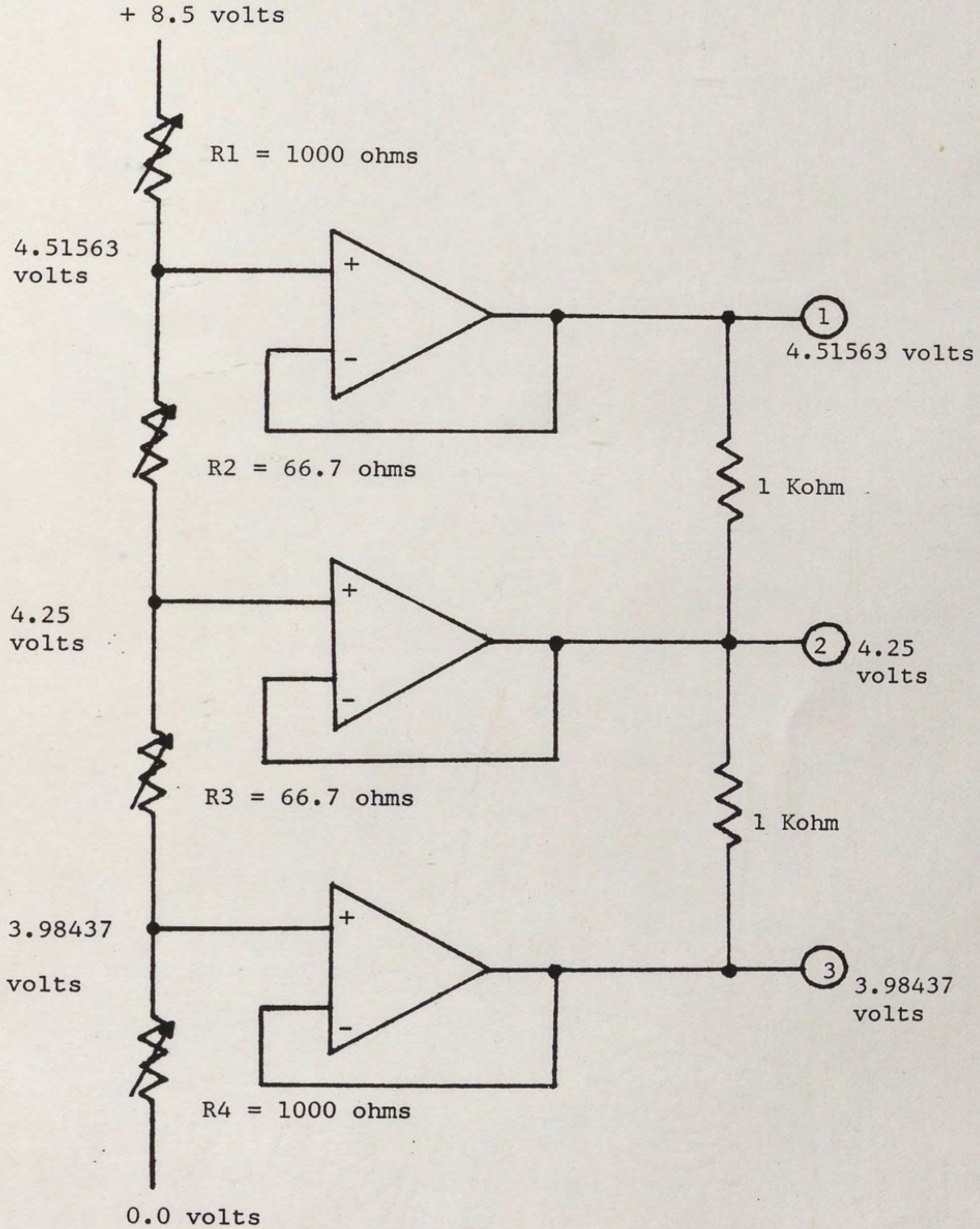

Figure 4a. Voltage Bias Circuit for 7-bit Companding ADC.

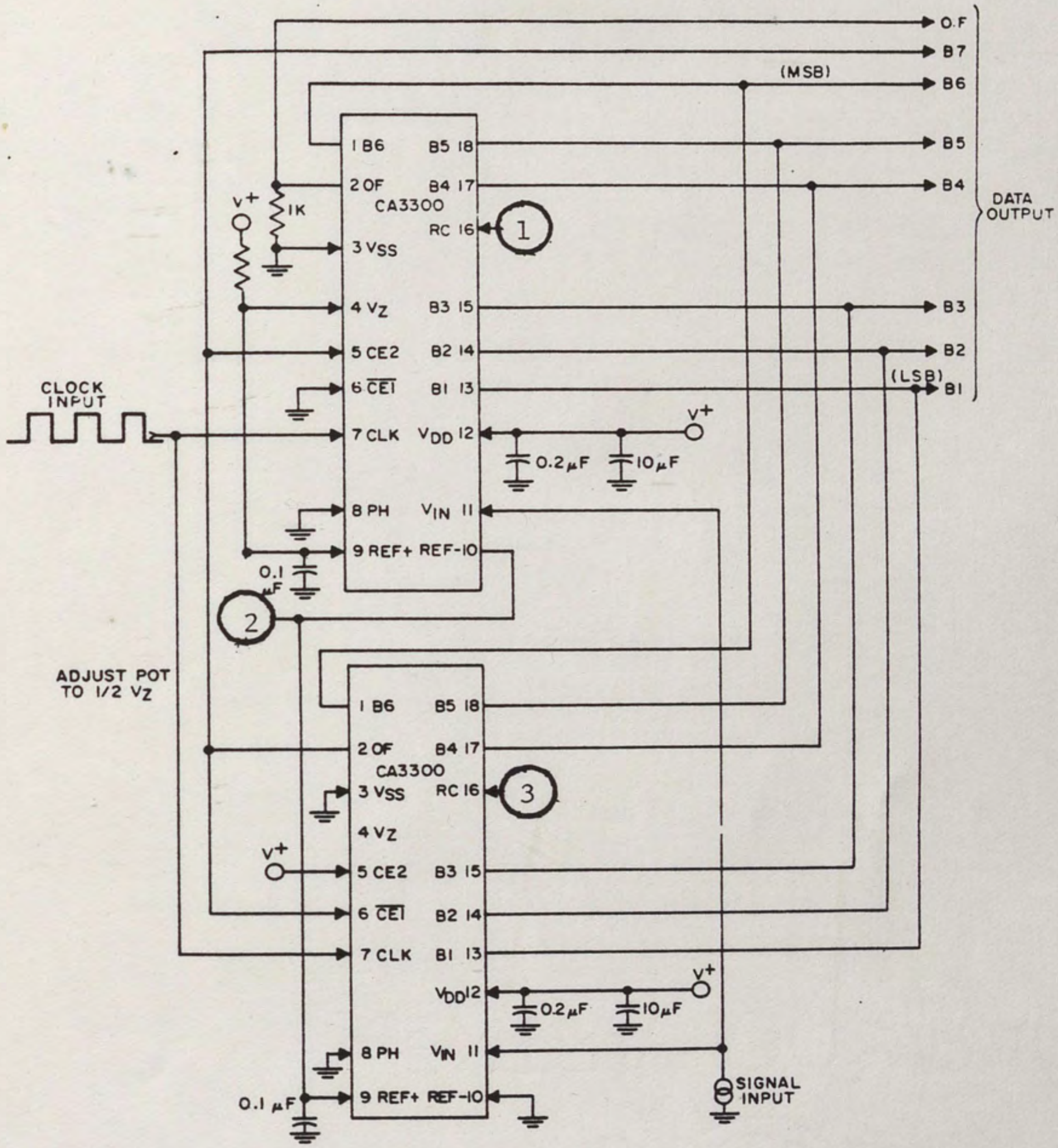

Figure 4b. 7-bit Companding ADC.

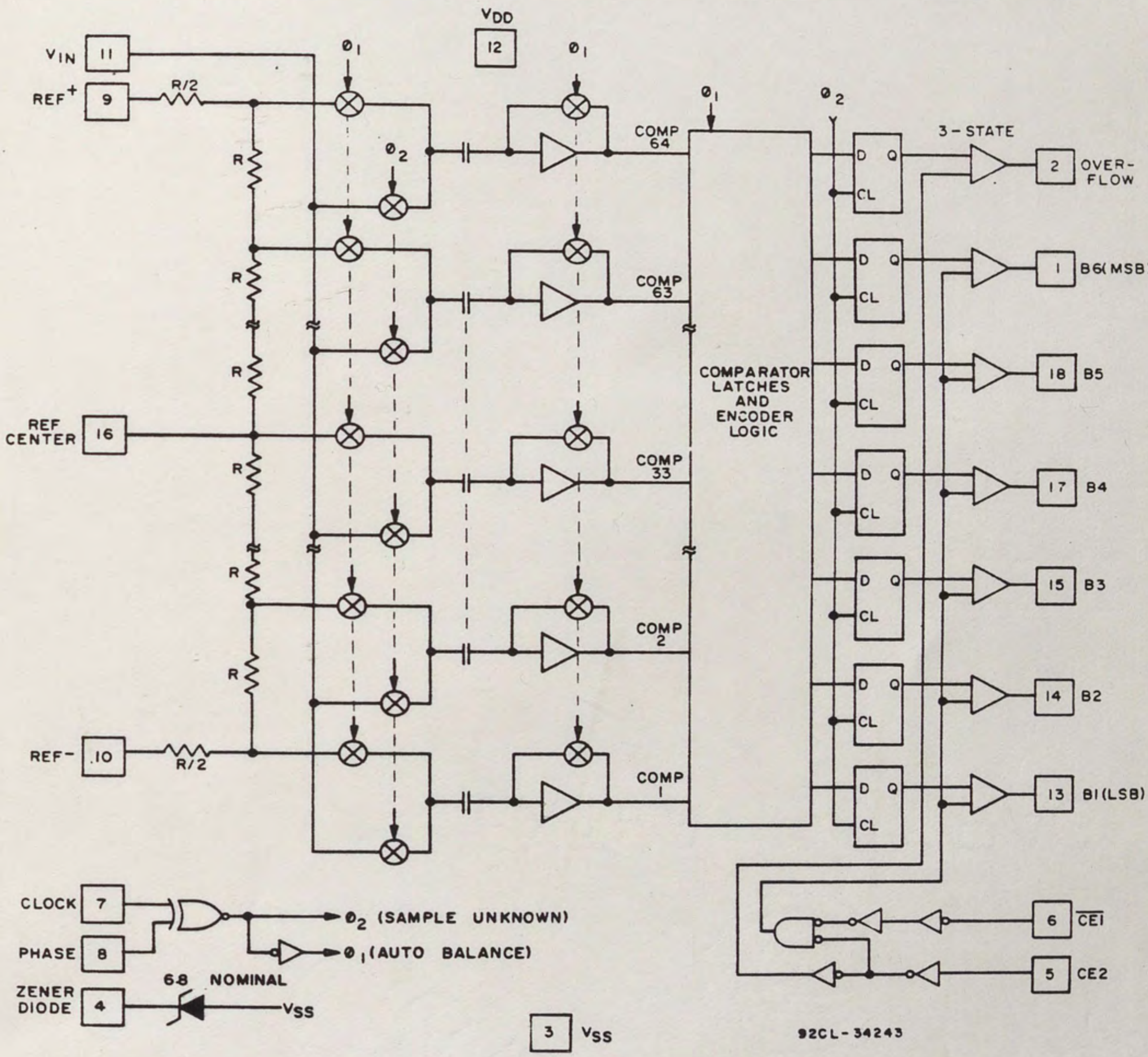

Figure 5. Circuit Diagram of the RCA CA 3300 6-bit Flash ADC.

resistor ladder. If they were absent, the op amps would have to either sink or source an undesirably large amount of current in order to maintain their outputs at the proper voltage levels.

CHAPTER 5

ROM EXPANDER

The expansion of compressed data can be performed in digital hardware using a Read Only Memory (ROM). The ROM would be used as a look-up table where each word from the ADC is used to address the contents in memory containing the expanded data word. Figure 6 shows the curve of compressed data vs. expanded data. Each segment will have a step size that inversely corresponds to the compression of the flash ADC. ROMs are extremely fast and that is the reason for the use of these devices at video frequencies.

The design chosen uses a 7-bit compression word and desires 10-bit resolution. Ten-bit resolution requires at least 10-bit data words as output of the ROM expander. Seven by ten-bit ROMs are not common components; therefore, any ROM with more than 7 address bits and more than 10 data bits can be used. Whatever the size of the ROM, only 128 addresses will be used with 10-bits of valid data.

A compander uses non-linear compression and expansion functions but, as a system, must be a linear operation. Figure 7 shows the voltage input vs. 10-bit digital output for the design analyzed.

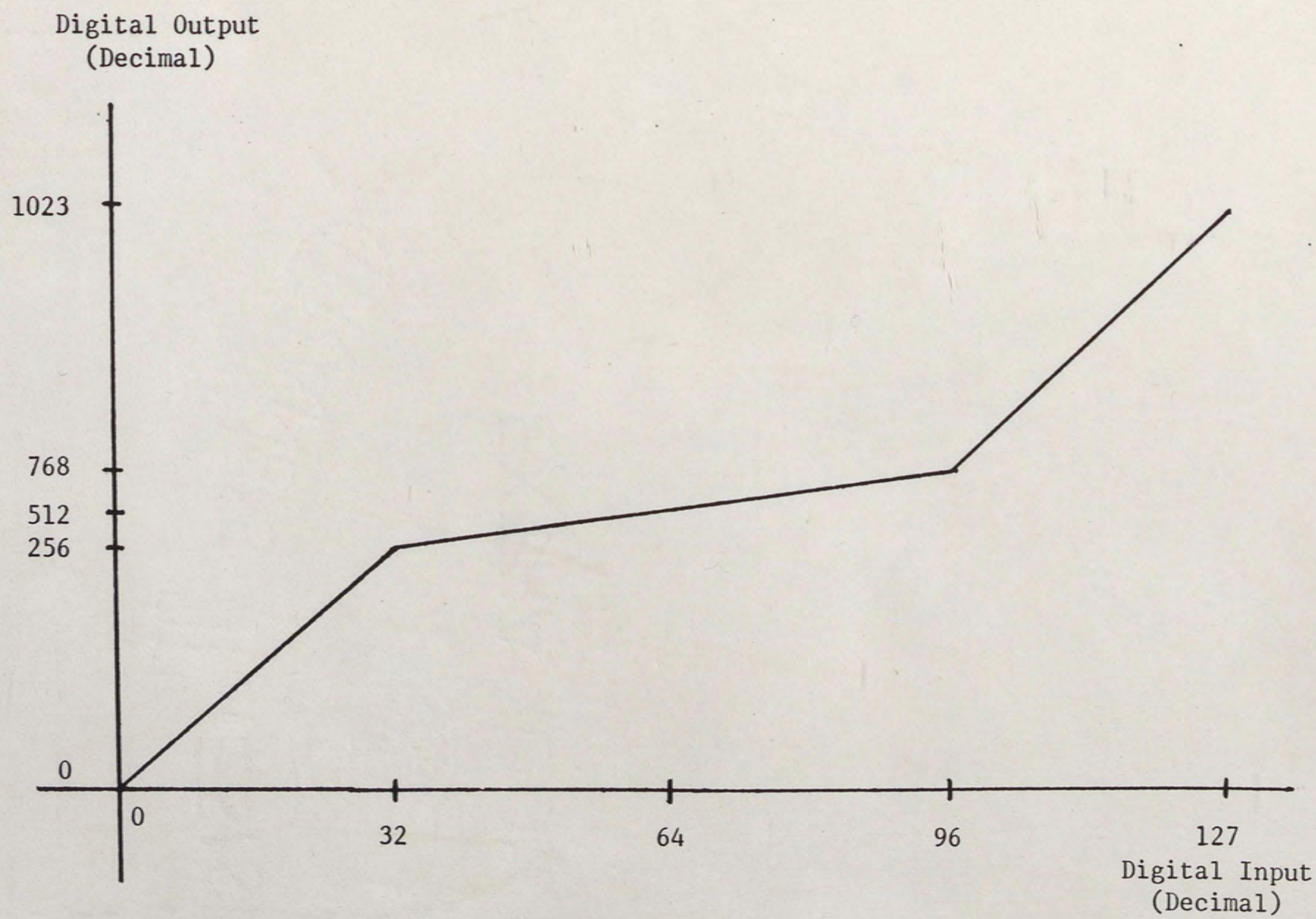

Figure 6. 7-bit to 10-bit Digital Expander Diagram.

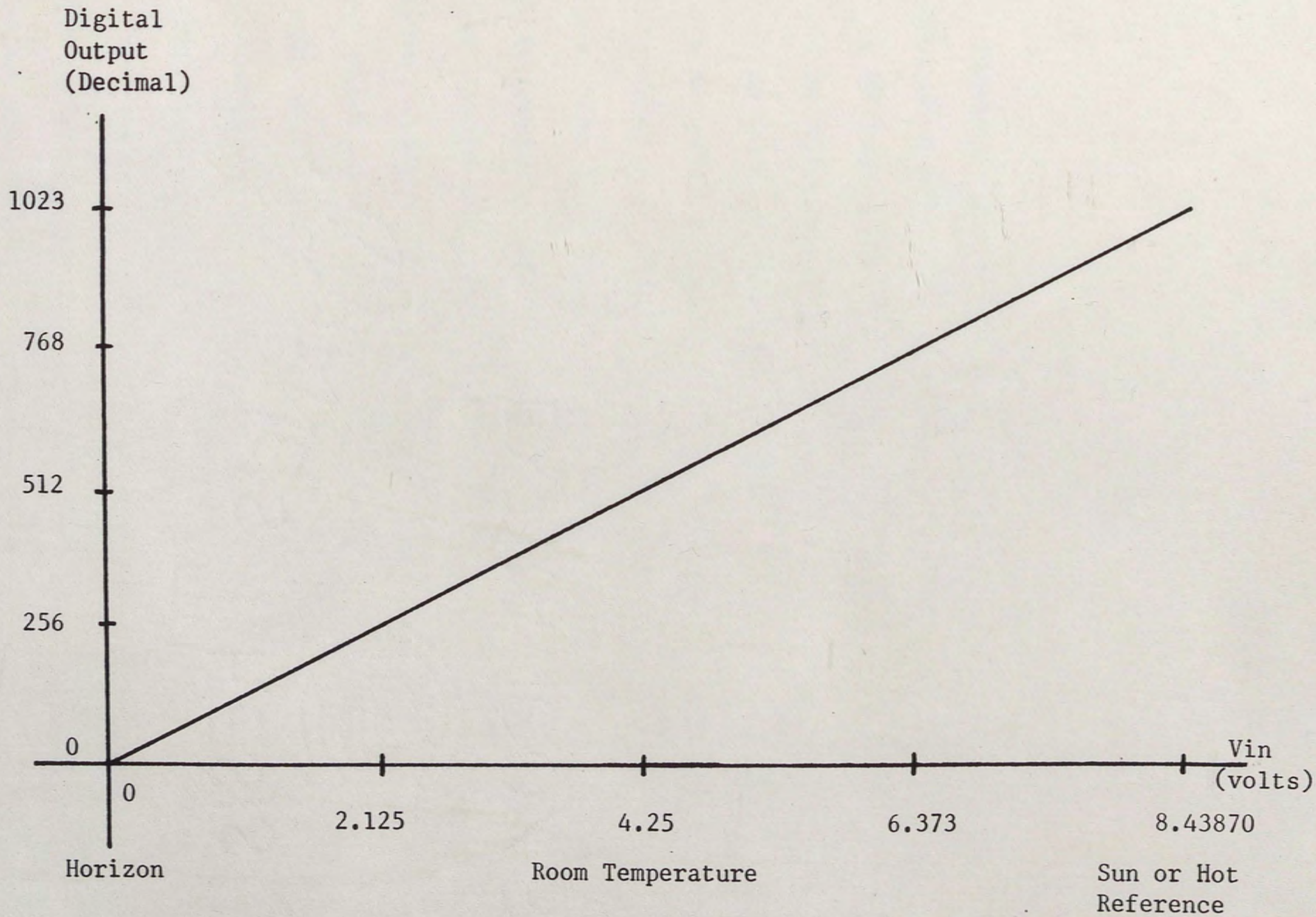

Figure 7. 10-bit Linear ADC Diagram .

CHAPTER 6

TEST SET-UP

Figure 8 shows the test set-up designed to test and evaluate a companding flash ADC. The equipment consists of:

2 HP 6236B Triple Output Power Supplies

2 HP 6282A DC Power Supplies

1 HP 3468A Multimeter

1 HP 3325A Synthesizer/Function Generator

A variable input voltage can be provided by an HP 6282A Power Supply. The HP 6282A is adjustable from 0 volts to 12 volts using a fine adjustment voltage knob. Each click of this knob varies the output voltage of a few millivolts which is necessary because the minimum quantanization step voltage is 8.3 millivolts. Two HP 6282A Power Supplies can be put in series to increase the voltage range past 12 volts but this is dangerous since the specified input voltage range is 2.4 volts to 8.5 volts. Damage to the RCA 3300 chips could occur if this voltage range is violated.

Two methods of adjusting the input voltage while monitoring the output are mentioned below. Figures 9a and 9b show a procedure which could be used if LEDs are driven by the outputs. The user must judge code transitions as the input voltage is adjusted through the voltage range. A disadvantage to this technique is that it requires driver circuits for the LEDs so that the outputs can assume proper logic

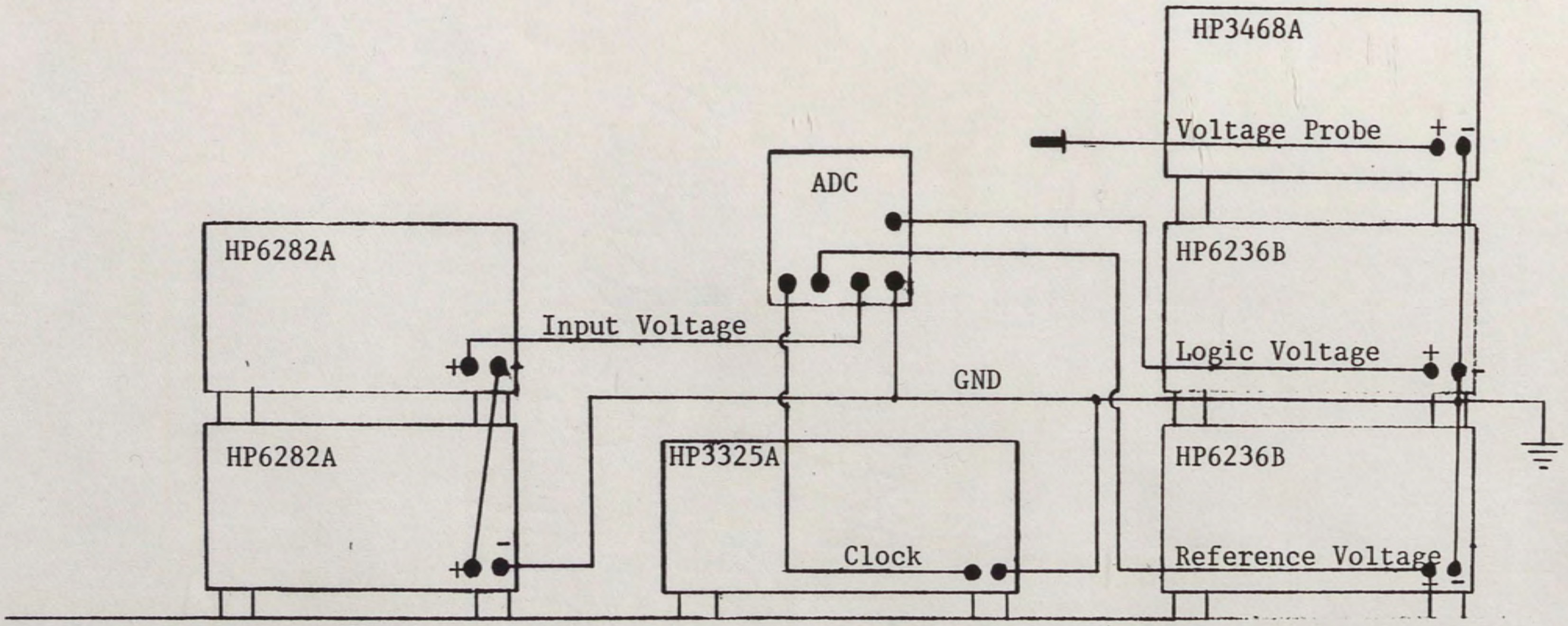

Figure 8. Test Set-up.

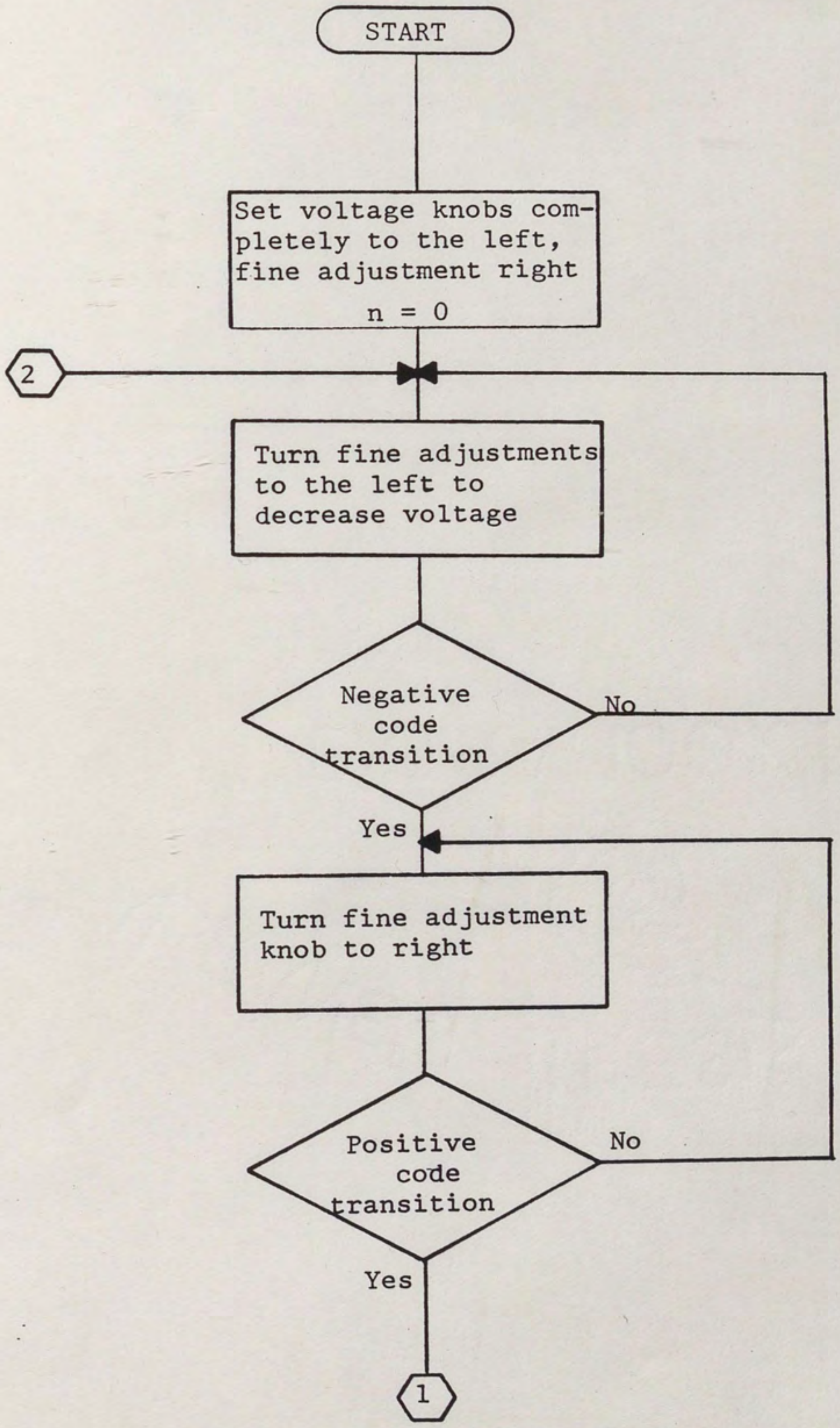

Figure 9a. Possible Procedure for Adjusting Input Voltage While Taking Data.

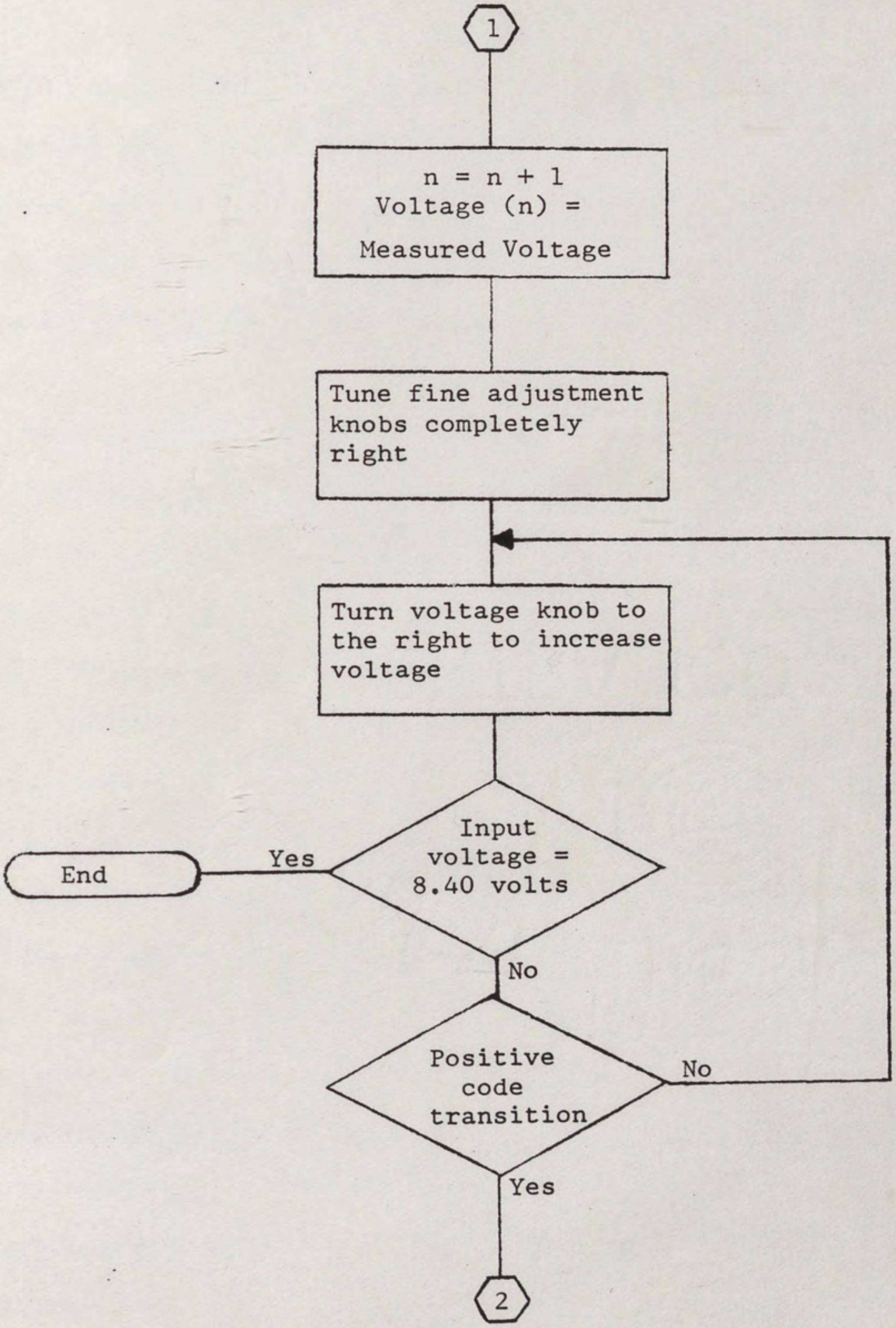

Figure 9b. Continuation of Figure 9a.

voltage levels. This procedure also requires subjective judgements as to whether LEDs are fully lit or not. Figures 10a and 10b show a procedure which takes into account the fact that the LSB is complemented every time there is a code transition. A disadvantage of this technique is that it assumes that there are no missing codes in the output.

Stable logic and reference voltages can be provided by an HP 6236B Triple Output Power Supply. The three outputs are adjustable from 0 to 6 volts, 0 to 20 volts, and -20 to 0 volts. If a logic level of higher than 6 volts is necessary, then an additional 6236B would have to be used in place of the 0 to 6 volt output.

A 50% duty cycle, square wave, clock signal of up to 10 MHZ can be provided by an HP 3325A Synthesizer/Function Generator. This device allows precise programming of both amplitude and frequency for sinusoids, triangular waves, ramps, and square waves.

An HP 3468 Multimeter can be used to monitor the voltage levels of all signals in the test setup. The resistance of each potentiometer can be adjusted accurately to precisely set each chord of the segmented companding curve. The voltage levels of the bias circuits can be verified. When static testing is performed, the voltage at every input and output of the CA3300, except the clock, can be verified.

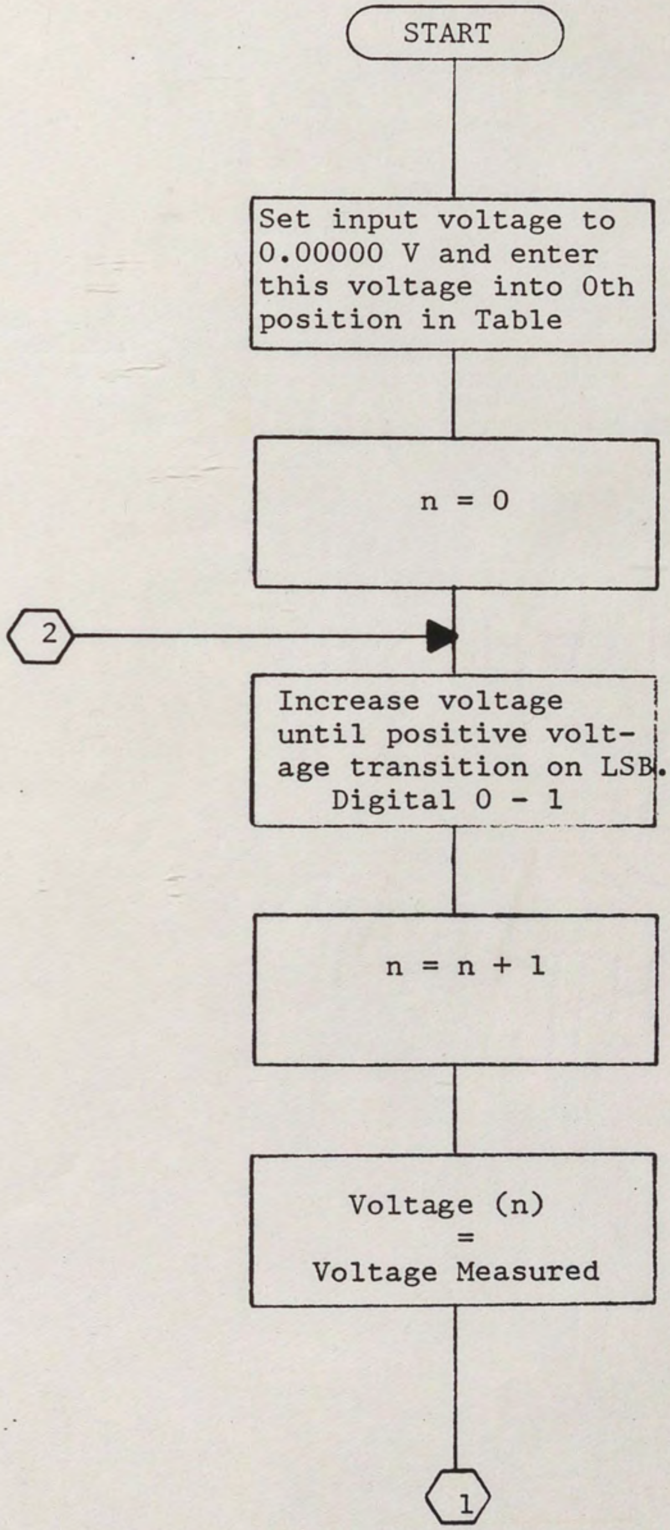

Figure 10a. Second Possible Procedure for Adjusting Input Voltage While Taking Data.

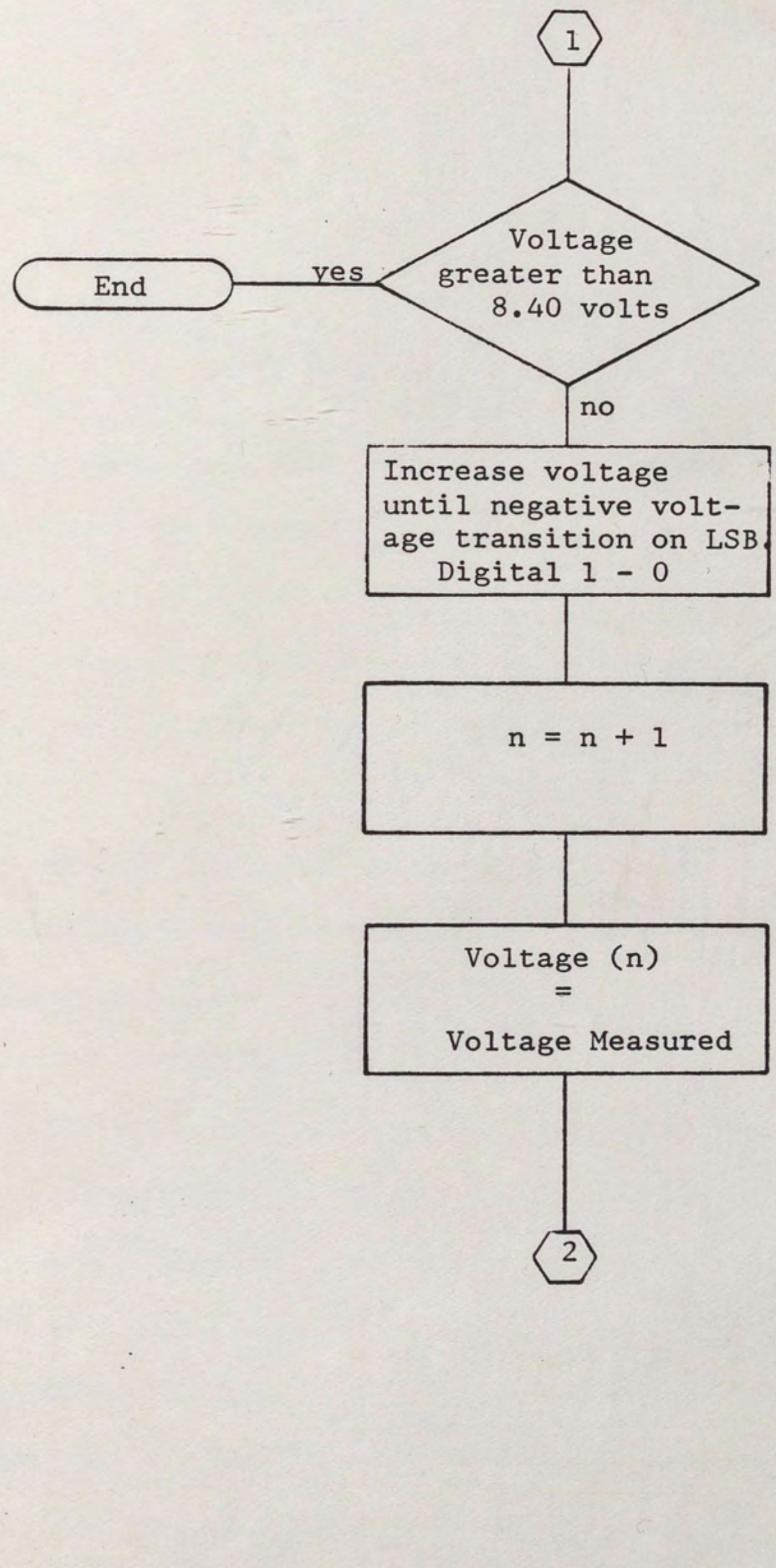

Figure 10b. Continuation of Figure 10a.

CHAPTER 7

CONCLUSION

The design of a 7-bit companding ADC has been completed with 10-bit resolution in the compression chord while still retaining better than 6-bit resolution in the remaining chords. This was built and tested. It was found that the output codes were in error within the compression section. The data sheets for the RCA CA3300 put the minimum resistor ladder voltage at 2.4 volts with negative reference as ground. This translates into a maximum voltage resolution of 37.5 millivolts. Eight-, 9-, and 10-bit resolutions with the maximum reference voltage of 8.5 volts are 33.2, 16.6, and 8.3 millivolts respectively. Each of these is less than the minimum voltage resolvable by the CA3300; therefore, the CA 3300 can not be expected to perform properly.

Error sources in a design like this must be minimized to allow for optimum performance. Wiring must be laid out to minimize noise coupling. Electrical noise sources should be placed at a distance from the test circuit. Reference voltages must be as stable as possible. If these and further precautions are not taken, data taken can be totally out of allowable limits.

The companding flash ADC is still practical even though it is not implementable using the RCA CA3300. The resolution of each comparator within the compression range needs to be improved. Perhaps it could be better implemented on ECL or TTL instead of CMOS. Also, companding flash ADs should be custom or semi-custom devices. A designer should be able to submit data in the form of a segmented companding curve and manufacturer produce the corresponding device.

A user friendly software package could be easily created which would automate both design and testing of these devices. Critical data such as resolution desired and ambient temperature for a given number of output bits would be entered. The output would consist of graphic plots of voltage input vs. digital output and digital input vs. digital output, tables of resistor values in the resistor ladder, and binary output on tape or disk which could be loaded on automated production equipment for manufacturing.

The software package could interface with special purpose test equipment to test the design. The microcomputer then could automatically program both static and dynamic tests while monitoring the output codes. The software could run automatic diagnostics and calibration on the test set so that, if there was a problem, it would be diagnosed before testing.

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