

AD 744873

REPORT NO. DOT-TSC-FAA-72-1

# CHARACTERISTICS OF A SIGNAL DATA CONVERTER FOR A MULTI-RUNWAY VISIBILITY MEASURING SYSTEM

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OCTOBER 1971  
TECHNICAL REPORT



U.S. International Transportation Exposition  
Dulles International Airport  
Washington, D.C.  
May 27-June 4, 1972



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Prepared for:  
DEPARTMENT OF TRANSPORTATION  
FEDERAL AVIATION ADMINISTRATION  
WASHINGTON, D.C. 20590

1. Report No. DOT-TSC-FAA-72-1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle CHARACTERISTICS OF A SIGNAL DATA CONVERTER FOR A MULTI-RUNWAY VISIBILITY MEASURING SYSTEM				5. Report Date October 1971	
				6. Performing Organization Code	
7. Author(s) H. C. Ingrao, J. R. Lifnitz				8. Performing Organization Report No.	
9. Performing Organization Name and Address Department of Transportation Transportation Systems Center 55 Broadway, Cambridge, MA. 02142				10. Work Unit No. R2125	
				11. Contract or Grant No. FA 215	
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Washington, D.C. 20590				13. Type of Report and Period Covered Technical Report June 1971-Nov. 1971	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract The characteristics of a signal data converter (SDC) are developed with application to airport visibility measuring systems. The SDC is discussed in the context of an evolutionary growth of the visibility measuring system stemming from the present FAA RVR measuring technique. A new SDC will be employed which will use state-of-the-art concepts and will be capable of handling future visibility measuring systems outputs to provide more comprehensive visibility information and display. Included in these outputs will be simultaneous signals from as many as nine transmissometers distributed three each along three runways. In addition, ground illuminance sensors will provide more background discrimination than the present day-night switch. Finally, the system will be expected to handle inputs from several kinds of target lights and to calculate and output for display several specialized visibility values (RVR,SVR,TVR). The SDC will be capable of modular expansion such that the capability for such future tasks will be available.					
17. Key Words <ul style="list-style-type: none"> <li>• Visibility</li> <li>• Air Traffic Control</li> <li>• Signal Data Converter</li> </ul>				18. Distribution Statement <p>Availability is Unlimited. Document may be Released To the National Technical Information Service, Springfield, Virginia 22151, for Sale to the Public.</p>	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 30	22. Price

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## INTRODUCTION

The Transportation Systems Center of the Department of Transportation is presently engaged in a study program for the Federal Aviation Agency titled "Visibility Measuring Devices".

This report summarizes the results of one of the tasks under the program. The specific task statement reads as follows: "Characteristics will be defined for a signal data converter for computing visibility values from inputs from several transmissometers with reference to several kinds of target lights (e.g. centerline lights, approach lights, edge lights, taxiing lights).

Considerations are given in this report to an evolutionary process from the present FAA RVR system to a multi-runway visibility measuring system. The full system is expected to be reached after a 4-step process. The first step in this development will be a modernization of present transmissometers using solid-state components. Subsequent modifications will employ state-of-the-art concepts for the Signal Data Converter (SDC). Ultimately, the SDC will be capable of handling the simultaneous signals from as many as nine transmissometers distributed three each along three runways. In addition, ground illuminance sensors will provide more precise background information than is presently available. Finally, the system will be expected to handle inputs from several kinds of target lights and to calculate and output for display several specialized visibility values (RVR, SVR, TVR).

# PRESENT FAA SYSTEM FOR RVR MEASUREMENTS

## INTRODUCTION

The present procedure used by the FAA to determine visibility at airports depends heavily on the transmissometer as a reliable instrument to complement, and at times replace human observers. The evolution of a comprehensive visibility measuring system, as discussed within the context of this report, will likewise center on the transmissometer as the basic tool for gathering visibility information.

In this section a brief description is given of the entire RVR system now in use. This system includes the transmissometer, the RVR Signal Data Converter, the remote digital display and the recorder. Figure 1 shows a block diagram of the current FAA RVR Measurement System.

## TRANSMISSOMETER

The transmissometer, first developed by Douglas and Young<sup>1</sup> at the National Bureau of Standards in 1942, measures the atmospheric transmittance over a fixed distance (usually 250 feet) with a light source and a photo-detector at opposite ends of the sampled path. First accepted for airport operations in 1952, the transmissometer now serves to measure RVR or RVV along more than 270 runways. Although it has been modified by the addition of heaters, blowers, power stabilizers, etc., the basic design and operating principles of the instrument have not been changed since the first transmissometers were installed. The "Preliminary Instruction Book - Runway Visual Range (RVR) System"<sup>2</sup> prepared for the FAA gives a concise description of the transmissometer. The manual describes it as follows:

"The transmissometer measures atmospheric transmission by projecting a well collimated beam of light down a base line installed near the ILS glide slope transmitter building or adjacent to the touchdown area of the ILS runway, and detecting the intensity of this light in a photoelectric receiver located at the opposite end of the baseline. The receiver translates the intensity of the received light into a pulse rate by using photoelectric current generated in a vacuum photo-electric cell to charge a capacitor. When a given charge accumulates on the capacitor, a gas discharge trigger tube connected across the capacitor breaks down delivering a large impulse to the following circuitry and reducing the



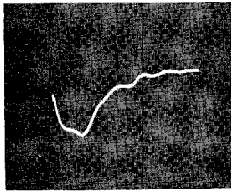


voltage of the capacitor to a low value equal to the extinction voltage of the gas discharge tube. This process is repeated; the time required to accumulate this charge being inversely proportional to the photocurrent and hence to the light intensity. Thus, the pulsing frequency of the circuit is linearly related to the light intensity.

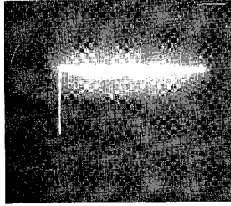
Through the use of an iris diaphragm in the optical system of the receiver, this pulsing rate is adjusted to 4,000 pulses minute<sup>-1</sup> for 100% transmission, i.e., a clear day free of smoke, dust or haze, in the baseline path. Any such aerosol, including fog or rain, in the base line path reduces this light intensity and hence the pulsing rate by absorbing or scattering light from the beam. Ideally, no extraneous sources of light should be permitted to enter the optical system of the receiver such that the pulsing rate would be zero in the absence of a beam from the transmitter. In any actual situation a background level of illumination exists necessitating subtracting the pulse rate measured with the transmitter source off from the pulse rate measured with the transmitter source on. This background correction must be performed from time to time to take into account changing sun position, sky brightness or weather conditions which result in spurious light scatter into the receiver. This background correction is performed manually by either switching off the projector from the indicator front panel switch and observing the recording milliammeter indication, or initiating a background check sequence by pressing a button on the signal data converter power supply and control chassis or any remote indicator chassis connected to the signal data converter control and power supply. More than one transmissometer may be used per runway as required for operation at runways approved for lower visibility operation."

As indicated in Figure 1, the pulses entering RVR signal data converter, directly from the transmissometer through a telephone line have a rectangular shape with amplitude of 16 volts and a width of about 100  $\mu$ sec. Oscillograms, recorded by TSC personnel, of transmissometer pulses at the end of the telephone lines at Logan Airport, Boston, are shown in Figures 2 and 3. It can be seen that the pulse shapes from transmissometers on runways 4R and 33L are somewhat different, although their general characteristics are consistent with the above shapes. Also noticeable in these oscillograms is a lack of noise on the telephone lines.

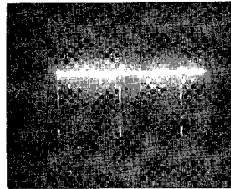
At Logan, these pulses are sent through an additional two stages of amplification before entering the RVR signal data converter.



a



b



c

Figure 2. Oscillograms showing the transmissometer output pulses at the end of the telephone line (Logan Airport, runway 4R);

- a) 30 volt pulse amplitude and 22  $\mu$ sec width,
- b) same as a) but slower sweep speed;
- c) sweep speed further reduced, showing successive pulses 15 msec apart.

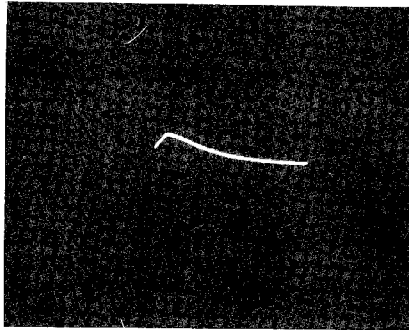


Figure 3. The same as Figure 2 but the transmissometer installed at runway 33-L; 15 volt pulse amplitude and 40  $\mu$ sec width.

#### RVR SIGNAL DATA CONVERTER

Quoting from the same manual<sup>2</sup>: "The signal data converter computer contains the necessary time base, clock dividers and counters to permit obtaining a digital value for the transmissometer output. A separate counter is used to count and store the background count which is subtracted from the normal transmission count by entering the complement of the background count into the transmission counter prior to the 45 second period over which the transmissometer output is counted. Transmissometer output is counted for a 45 second period and then transferred into a static storage register. Three seconds later, the transmission counter is cleared, the background complement entered, and the process repeated. The value of transmissivity obtained through this count is stored such that a computation of the RVR value can take place at any time. While under normal conditions, a computation of RVR takes place only once in 48 seconds, a recomputation is initiated whenever a different RVR table is selected in response to a change in runway light setting or a change in the status of the day/night switch. These two

inputs serve to select one of the six RVR tables which are plugged into the signal data converter. Systems are furnished either with class I tables pertaining to a 500 foot base line or class II tables pertaining to a 250 foot base line for the transmissometer. With a table selected, the RVR value is obtained from the table by applying clock pulses to the input of the transmissivity storage register causing it to count upward from the value of transmissivity previously stored. The number of pulses supplied to the transmissivity register is precisely equal to the capacity of the register, 2048 pulses. Thus, at the end of such a counting-compute cycle, the value stored in the transmissivity register is exactly the count which was originally stored in this register. The output of the transmissivity register is translated into a hexadecimal code and applied to the selected RVR table, an output pulse is obtained from the selected RVR table, meaning that the RVR value exceeds or is equal to the value represented by such a count. This pulse output from the RVR tables is passed through a gate and into a five bit counter. The purpose of the gate is to prevent any pulses from reaching the five bit counter until the transmissivity register has passed the overflow point; thus the number of pulses entering the five bit counter is equal to the number of RVR values which are passed between the time the transmissivity register overflows, and hence reads zero, and the time it counts up to its original stored value. Thus, the count in the five bit counter is equal to the number of the solution from zero to 21 which corresponds to the RVR value to be displayed.

The value of the RVR is transmitted to the Remote Digital Display as discussed below. During the time the SDC is not transmitting an RVR value, the receiver decoder transmits the value of runway light setting received from the runway light intensity relay box in the form of one of three frequencies with which the line is switched to common. This switching of the line is detected by the SDC and used to select the particular table required depending on the status of the day/night switch. Up to five remote indicators or computer selectors can be connected to either a signal data converter or a receiver decoder. Additional features of the signal data converter computer include two test provisions, one of which substitutes a crystal clock frequency for the transmissometer pulse output, and the other cycles the indicators through all the possible RVR values. In order to test all tables, a manual table select is available in conjunction with the first test".

#### RVR REMOTE DIGITAL DISPLAY

The RVR data is distributed from the RVR computer to the controllers in the control tower (CAB) as numerical read-outs on the Remote Digital Display Unit and then via voice link to the pilot in the aircraft. The RVR display at Logan International Airport, Boston, e.g., has the capacity to monitor up to sixteen individual instrumented runways, two runways at a time (one transmissometer each), as selected by runway selector switches.

Readings range from 1000 to 6000 feet and are updated approximately once a minute. RVR is given in hundreds of feet by the first two digits on the display with the third digit indicating a "+" (in excess of 6000 ft) or a "-" (less than 1000 ft).

Under conditions not requiring RVR computation, i.e., when the airport's runway lights are in intensity positions "1" or "2", an "L" appears in the third digit position of the display, indicating that the RVR computer is inoperative because it is not required.

The signals to the display unit are derived from the SDC as follows. The contents of the five bit counter holding the value of the currently-calculated RVR are decoded to yield a signal on one of the 21 lines corresponding to the 21 solutions. These lines are re-encoded into a modified indicator code which is used to operate a bank of nine relays, three for each digit and three for the symbol following the two digits. The relay contacts are appropriately wired to route the proper positive and negative voltages to the proper indicator terminals in order to display the appropriate numbers. The indicators remain quiescent until a solution is obtained at which time they are strobed for 0.75 seconds to display the new value. Simultaneous with the strobing of the indicators, the nine bit modified indicator code is transmitted in serial binary to the receiver decoder along with a parity bit for error detection. If a parity error is detected or the line is interrupted, the receiver decoder automatically forces the display to read "\_\_\_ E."

#### RVV INDICATOR AND RECORDER

The pulse train from the transmissometer is also monitored by the RVV indicator. This indicator is essentially a frequency meter that converts the pulse train signal to a direct current whose magnitude is proportional to the pulse rate. A strip-chart recorder provides a continuous record of the indicator output which is proportional to the instantaneous transmission of the atmosphere.

## AN EVOLUTION FROM THE PRESENT FAA RVR SYSTEM TO A MULTI-RUNWAY VISIBILITY MEASURING SYSTEM

### STAGES IN THE EVOLUTION

The present RVR system has served well its function of gathering visibility data, computing RVR values and disseminating the information. It is clear, however, that future demands of ever increasing traffic, lowered landing minima and extensive automation of the landing process will require new approaches to the entire visibility measuring problem. One of the approaches foreseen is the extension of the present RVR system into a more comprehensive system, increasing its accuracy, adding flexibility and generally improving the quality of the disseminated information as well as its output rate. The ultimate goal is a system using the best state-of-the-art equipment and monitoring visibility for all of the runways and taxiways of an airport.

In the interest of continuity and to ensure that changes in the system will not compromise airport safety or efficiency, the FAA intends these changes to be made as a series of successive modifications. For example, a practical approach to these evolutionary phases is indicated in Figure 4 (Page 10).

The first modification consists of replacing the present vacuum tube circuitry of the transmissometers with solid-state components.

The second phase of the program will be the introduction of a new signal data converter (SDC) whose general characteristics will be established in this report. On the one hand, this SDC must be capable of performing all the functions of the present RVR computer. This includes processing signals from existing transmissometers, with baselines of 250 and 500 feet, as well as from shorter baseline transmissometers (75 feet). The new SDC will not only drive existing RVR remote digital displays, but will have a teletype input-output facility allowing changes in the equations, constants, added corrections, etc. by software changes alone. Also punched paper tape permanent storage of continually up-dated information related to visibility at the airport is provided.

The most significant improvement in the new SDC will be its more powerful computer, which will have considerably more speed and capacity than the present RVR computer. It will be

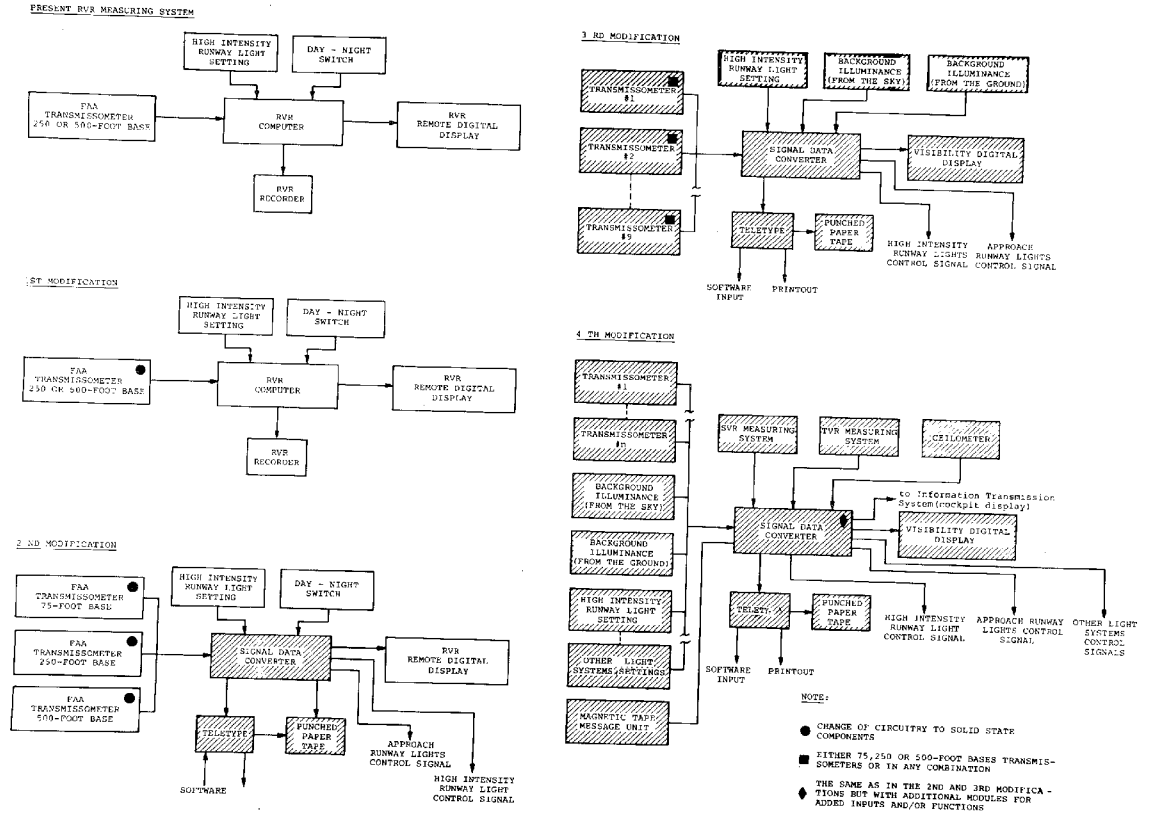


Figure 4. Block diagram of an evolution from the present FAA RVR System to a Multi-runway visibility measuring system.





possible to take advantage of this increased potential in several ways. Since the RVR computations will be more precise better input data will be needed. Thus, for example, the present "day-night" switch must be replaced with a background luminance monitor which will provide a continuous and suitably fine differentiation of background conditions. It will also be possible for the computer to be used for certain control purposes, such as controlling the settings of the high intensity and approach runway lights, as background and RVR conditions warrant.

The third evolutionary phase will be the extension of the transmissometer network to include several runways and up to three transmissometers per runway (at touchdown, mid-point and rollout). At this point, it is likely that a new version of transmissometer may be introduced, and the SDC introduced in phase II will have to handle the outputs of this multi-transmissometer array. This need will have been anticipated in the SDC, which will be designed to receive inputs from up to 9 transmissometers simultaneously and to perform read-in, computation and output operations at substantially faster rates than possible with the present RVR computer. In addition, the SDC output must be compatible with new and more comprehensive concepts of visibility displays for both pilots and control towers<sup>3</sup>.

Finally, in the last stage of development (Modification 4), the visibility measuring system will take into account all the various light targets used for visual cues, such as edge lights, taxiway lights, centerline lights, etc., as well as the high intensity runway lights. It is expected that the SDC will be able to use this information to calculate and display taxiway visibility (TVR) and slant visual range (SVR). Also, there may be a need in the future to determine and display ceiling information; for example, as part of the measurement of SVR or ALCH.

The operational definition of TVR is not yet certain; furthermore, the methods for determining SVR (and TVR) are not established. In the case of SVR, there may be a need for rather specialized data analysis. This will be so, for example, if SVR values are to be derived from the shape or amplitudes of backscattered laser pulses<sup>7</sup>. It is possible that the SDC will have to be expanded in the fourth stage of modification to handle these increased data input-output demands. However, there are several minicomputers available on the market today which have expandable memories and modular architecture. It appears, too, that the very near-future will bring minicomputers with even more capacity, more flexibility and lower prices. Therefore, it is believed that the requirements of this

final stage in the evolution of the visibility measuring system can be met by modular adjuncts to the third phase system with a minimum amount of additional SDC hardware.

In Figure 4 (Modification 4) two new functions are shown for the overall visibility measuring system. One is a magnetic tape message system which will send emergency or special message units to the pilot. The same messages can be sent to the SDC.

The second new feature is the provision for sending visibility information to the cockpit display. The scope of this task will depend on the form of cockpit visibility display selected by the FAA<sup>3</sup>.

#### PROPOSED VISIBILITY INFORMATION

The present operational meaning of "visibility" is simply the RVR; that is, how far along a runway, from the point of touchdown, the runway lights can be seen. This distance and perhaps also a ceiling indication, represents the only information which the pilot has concerning the visual environment into which he is descending. This provides a minimal description of landing visibility which will rapidly become inadequate to meet the demands of the future. A number of improvements have been suggested to complement the present RVR method of describing airport visibility and to enhance the significance of visibility information for the pilot.

As has been described above, an extension of the RVR concept has been proposed, in which a multi-transmissometer technique is used to indicate the visibility condition at three points along the runway. It appears that such a method would be welcomed by the pilots since they could land with more confidence in patchy fog or non-uniform weather conditions. Almost as important as the knowledge of the "longitudinally segmented" visibility is an indication of how rapidly it is varying. This calls for a method of computation and display which brings attention to significant temporal variations in reported visibility values. Included in any attempt to handle time-varying conditions is the question of desirable up-date intervals. Whereas at present this interval is 53 seconds, the combination of larger planes and lower landing minima (Category II and III) seems to generate a need for faster updating of information. A more effective interval is about 10 - 12 seconds<sup>3</sup>.

In addition to RVR, SVR is desirable since it is a measure of how well the pilot can see the approach lights along the

glide path. The SVR may well be less than the RVR in cases of inhomogeneous visibility conditions (for example, low ceiling). Since the SVR is the relevant information with regard to pilot orientation during approach, it should be included in any scheme for the modification of the visibility measuring system. The FAA is presently supporting the development of concepts and systems to measure the SVR but as of this date no satisfactory method has been identified

TVR would provide another piece of data for the pilot and controller to use in forming a complete picture of the visibility. As of this writing, no operational definition exists for this parameter.

Additional information which must be taken into account in characterizing the overall visibility measuring system includes the prevailing visibility (which is dialed in by the controller) and the light settings for High Intensity, Approach and Sequenced Flashing lights.

#### VISIBILITY AND BACKGROUND INFORMATION AS CONTROL PARAMETERS FOR INTENSITY SETTING OF RUNWAY LIGHTS

At present, the intensity of runways lights is set by steps (usually three) by the controller in the CAB and in accordance with the visibility and background conditions at the airport. The setting chosen by the controller can be changed on specific request of the pilot approaching for landing. The pilot communicates via voice with the controller and asks for a reduction or an increase in the intensity of the runway lights to improve his visibility under the prevailing conditions at that particular time. The same is true for the sequenced flashing lights (on or off).

In a proposed visibility data flow system<sup>3</sup> the authors indicated the use of the visibility and background information as controlling parameters of a servo system which will control the intensity of the runway lights. Provisions would be made to allow controller override of the servo system when unusual visibility and/or background conditions as experienced by the pilot warrant such intervention.

# AN ANALYSIS OF THE REQUIREMENTS OF A SIGNAL DATA CONVERTER FOR A MULTI-RUNWAY VISIBILITY MEASURING SYSTEM

## COMPUTATION OF RVR BASED ON TRANSMISSOMETER DATA

The specifications of a signal data converter are required, whose function is to compute RVR at a finite number of sites. The RVR is to be computed in a quasi-continuous manner from the solution of a set of simple equations along with regularly-updated values of the parameters, as given below:

$$\log t_b = \frac{b}{v} \left[ 2 \log \frac{v}{5280} + \log \frac{E_t}{I} \right], \quad (1)$$

$$v = \frac{b \log \epsilon}{\log t_b} \quad \text{and} \quad (2)$$

$$\log E_t = -5.7 + 0.64 \log B \quad (3)$$

The three equations above represent logarithmic formulations of Allard's law, Koschmieder's law, and the empirically-established relationship established by BLEU between visual illuminance threshold  $E_t$  and background  $B$ , respectively. Equation (3) is not the only one to give  $E_t$  as a function of  $B$ ; other equations or relationships could be used. (See Table 3)

The parameters appearing in these equations are:

- $v$  = runway visual range (RVR), in feet,
- $b$  = transmissometer baseline, in feet,
- $t_b$  = atmospheric transmissivity over baseline  $b$  ( $0 < t_b < 1$ ),
- $E_t$  = visual illuminance threshold of pilot, in mile-candles,
- $I$  = intensity of runway lights ["target"], in candelas,
- $B$  = background luminance (candles/feet<sup>-2</sup>),
- $\epsilon$  = visual contrast threshold, usually taken as  $\epsilon=0.05$ , but left in general form for present purposes.

The ranges and precisions required for the above quantities will be defined later.

The fundamental problem is to compute the value of  $v$  from the three equations and continuously updated input variables. It should be pointed out that equations (1) and (2) relate to

different visibility conditions. Allard's law is useful when the target is an intense light source (e.g., at night and in most daytime fogs). In good daytime visibility, pilots sense the contrast of runway markings more readily than runway lights, making Koschmieder's law (2) the relevant one. Since only one value of  $V$  is to be reported for any given transmissometer site, it must be the larger of the solutions of equations (1) and (2).

The total system with which the signal data converter must interface begins with the runway configuration of the airport. A working example is shown in Figure 5, in which three runways are instrumented with three transmissometers each.

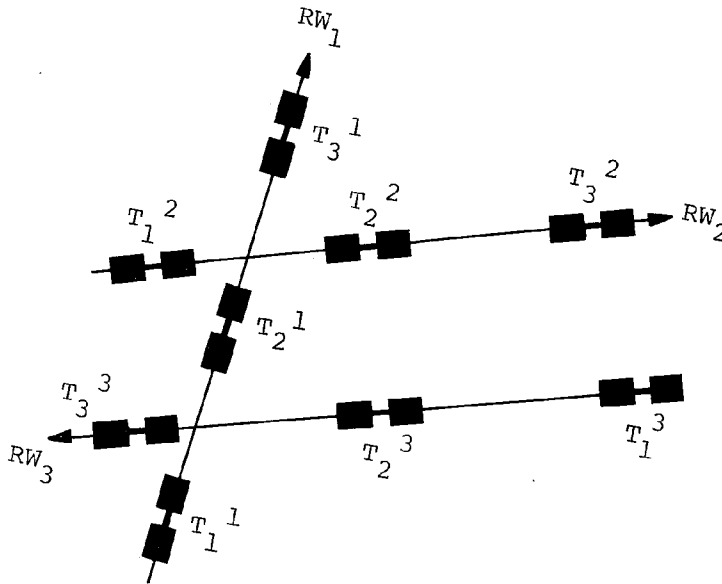


Figure 5. Runway Configuration

For a given runway, the transmissometer positions are denoted, in the direction of landing aircraft, as "touchdown", "midpoint" and "rollout." We will use a compressed notation below where  $P_{\alpha}^i$  is the parameter corresponding to the  $i$ th runway and the  $\alpha$ th position of the transmissometer. Here  $i, \alpha=1, 2, 3$ , and  $\alpha = 1$  means touchdown position,  $\alpha = 2$ , midpoint and  $\alpha = 3$ , rollout. Thus,  $T_1^3$  represents the transmissometer at the touchdown position of runway 3;  $b_1^3$  would be the length of the baseline of that transmissometer, etc.

The output of each transmissometer is first converted from photocurrent to a pulse train, the frequency of which is proportional to the transmittance  $t_{\alpha}^i$ .

The update requirements for the transmitted data vary widely. Thus, the baselines  $b^i$  will generally remain fixed, at least as presently conceived. Also, the light setting  $I$  will not change too often, surely not at the rate of the variations in  $t^i$  and (perhaps)  $B^i$ . Present transmissometers provide up-dated outputs at approximately 1 minute intervals. The conversion from signal photocurrent to frequency provides a simple way to couple the transmission data to the SDC via telephone line.

Next, we present an example of a flow scheme which might be used to solve equations (1), (2) and (3) for  $V^i$ . Table 1 shows the computation process in segments: The left-hand column represents the data to be fed into the calculation shown to the right (center columns). In the right-hand column the significance of the step is indicated.

TABLE 1. RUNWAY VISUAL RANGE NUMERICAL ANALYSIS

DATA	COMPUTATION	NOTE
$B^i$ $\log B^i$	$-5.7+6.4 \log B^i = \log E_t$	
$I^i$	$\log E_t \equiv L(E_t)$ $-\log I \equiv -L(I)$	$C \equiv L(E_t) - L(I)$
$V$ $\log V$	$2\log V \equiv 2L(V)$ $C$	
$b^i$	$(b/V) \Sigma = (b/V) [C+2L(V)] \equiv A_1$	2
$t_b^i$ $\log t_b^i$	$\log t_b^i = A_1$ $A_1 - A_1 = \Delta$	3
$\epsilon$ $\log \epsilon$	If $\Delta \geq \delta$ . return to $V$ , set $V' = V + dV$ , repeat. If $\Delta < \delta$ set $V = V^1$ $b \log \epsilon / \log t_b = V_K^i$ $V_K - V_A > 0$ display $V_K$ $< 0$ display $V_A$	4 5

NOTES

- 1)  $V$  is the last value of RVR calculated (i.e., presently displayed).
- 2)  $A_1$  is the right-hand side of Equation 1

- 3)  $A_1'$  is the left-hand side of Equation 1
- 4)  $\delta$  depends on precision with which  $V$  is determined.  
When  $\Delta < \delta$ , iteration is stopped and  $V_A$  is stored
- 5)  $V_K$  is the left-hand side of Equation 2.

The scheme presented in Table 1 is only intended to indicate a logical sequence of data usage. Equation (1), for example, might be handled better with the Newton-Raphson method, or other methods more compatible with the architecture of the computer.

#### RANGE AND PRECISION OF PARAMETERS AND VARIABLES

At present, RVR values are used when the prevailing visibility is 1 mile or less. The reported increments are as follows: When a 250 foot baseline transmissometer is used, RVR is reported in 200 foot increments from 600 to 3000 feet, and 500 foot increments from 3000 to 6000 feet. For a 500 ft baseline, RVR is reported in 200 foot increments from 1000 to 4000 feet, and 500 foot increments from 4000 to 6000 feet<sup>4</sup>.

The accuracy of the RVR determination must obviously be compatible with the step sizes of the reported values. In addition, as the landing minima are reduced and CAT III operations are begun, smaller step sizes will be required for lower visibilities, with correspondingly more severe (absolute) accuracy requirements. The factors which affect this accuracy include:

- a. Precision of the transmissometer reading,  $t_b$ .
- b. Finesse with which  $B$  is measured.
- c. Condition of the runway lights (I).
- d. Accuracy of RVR computation.

Thomas<sup>5</sup> has discussed these factors in an informative and penetrating analysis of the procedures underlying the determination of RVR. Table 2 is derived from his paper and shows the step sizes of RVR (in meters and feet) for CAT I, II and IIIA, IIIB, IIIC.) In addition, the table shows the contributions to RVR error from inaccuracies in  $t_b$  and  $B$ . These errors are related to the interrelation of RVR,  $t_b$  and  $B$  through Allard's law (1) and the empirical expression of Equation 3.

Though Thomas' results are based on a 20 meter effective baseline, nevertheless they indicate the general importance of precise values for  $t_b$  and  $B$ . In particular, the present procedure for selecting the background setting "day" or "night",

with the changeover at  $B=20 \text{ cd m}^{-2}$  or  $2 \text{ cd ft}^{-2}$ ) would not be suitable for this scale of accuracy. Among the improved versions for a background scale is a selection of four values: night, intermediate (dawn, twilight), normal day and bright day. The All-Weather Operations Panel (AWOP) of ICAO has recommended such a scheme and this is presented in Table 3<sup>6</sup>. A much finer grid of background values, with the range between night and bright day divided into 32 discrete steps, is recommended by Thomas. In this case,  $E_t$  no longer contributes significantly to error in the computed visibility.

TABLE 2  
RVR STEP SIZE AND RVR ERRORS CONTRIBUTED BY ERRORS IN THE  
MEASUREMENTS OF t AND B (5)

VISIBILITY CATEGORY	RVR		Errors in RVR due to errors in				RVR Step Size		
	M	ft	$t_b$		B		M	ft	
			M	ft	M	ft			
III	C	30	99					30	99
	B	60	198						
		90	297	<u>+5</u>	<u>+16.5</u>	<u>+2</u>	<u>+6.6</u>		
		120	396						
		150	495						
	A	180	594						
210		693	<u>+10</u>	<u>+33</u>	<u>+2</u>	<u>+6.6</u>			
II		270	891					60	198
		330	1089						
		390	1287						
		450	1485						
		510	1683	<u>+20</u>	<u>+66</u>	<u>+5</u>	<u>+16.5</u>		
		570	1881						
I		630	2079					100	330
		690	2277	<u>+30</u>	<u>+99</u>	<u>+6</u>	<u>+19.8</u>		
		750	2475						
		800	2640						
		900	2970						
		1000	3300	<u>+50</u>	<u>+160</u>	<u>+12</u>	<u>+39.6</u>		
	1100	3630							
	1200	3960							
	1300	4290							
	1400	4620	<u>+100</u>	<u>+330</u>	<u>+15</u>	<u>+49.5</u>			
	1500	4950							



TABLE 3  
 THRESHOLD ILLUMINANCE vs BACKGROUND AS RECOMMENDED BY THE  
 ICAO ALL WEATHER OPERATIONAL PANEL (AWOP)<sup>6</sup>

CONDITIONS	ILLUMINATION THRESHOLD, $E_t$	BACKGROUND ILLUMINANCE, B
	mile-candle	candle-ft <sup>-2</sup> *
night	2	0.4 to 5.0
intermediate (dawn and twilight)	26	5.1 to 99.9
normal day	260	100 to 1200
bright day (e.g. sunny fog)	2600	1200

\*The original source gave the values in candle m<sup>-2</sup>. In this table the values are given in candle-ft<sup>-2</sup>.

Likewise it would be desirable to monitor the intensity of the high intensity lights. The variation in intensity with long-term use is apparently less serious than abrupt effects such as weather. Either the lights must be maintained to prevent these changes or the value of I must be determined regularly.

Additional error must not be introduced during the process of converting the measured data into visibility values. This latter requirement depends on the proper selection of the computer for the Signal Data Converter.

The ranges of the parameters and variables which enter the computation of RVR are summarized in Table 4.

TABLE 4 RANGE OF PARAMETERS AND VARIABLES

PARAMETER OR VARIABLE	Values		Number of Steps		Specification References
	Maximum	Min.	Present System	Modified System	
Illumination threshold, $E_t$ , mile-candle	2600	2	2	At least 4; possibly as many as 32	-
Background luminance, $B$ , candle-ft <sup>-2</sup>	1200	0.4	2	At least 4; possibly as many as 32	-
Intensity Runway Lights (#L819), I candela	20,000		5	5	AC 150/5345-9 12/23/69
Approach Lights, I, candela	30,000 (white) 6,000 (red)		5	5	FAA
Center Line Runway Lights (#850), I candela	5,000 (white) ----- (red)		5	5	AC 150/5345-37B
Taxiway Edge Lights (#L822), I, candela	2 (blue)	0	1	1	AC 150/5435-23 10/13/64
Taxiway Center Line Lights (#L852), I, candela	100 (white)	0	1	1	AC 150/5345-29
Intensity, other Lights, I candela	-	-	-	-	-
Base line, $b$ , feet	500	75	2	3	-
Pulse Rate, $t_b$ , pulses/min <sup>-1</sup>	12,000	0	continuous	continuous	-

# CHARACTERISTICS OF A SIGNAL DATA CONVERTER FOR A MULTI-RUNWAY VISIBILITY MEASURING SYSTEM

## INTRODUCTION

A signal data converter (SDC) which will satisfactorily serve a multi-runway visibility measuring system must be capable of handling the inputs from a minimum of 9 transmissometers.

Information concerning background illuminance, high intensity runway light settings (for 3 runways), baselines, and other data must be presented to the SDC. In addition the computer must be reliable, flexible and expandable, with sufficient capacity to handle the computational tasks precisely and quickly enough to meet foreseeable demands of airport visibility standards and procedures.

As far as possible, the development of new visibility measuring equipment or better insights into the illuminance threshold testing must not render the computer obsolete. (At the same time, of course, the SDC must be compatible with present day measurement procedures so as to permit an orderly evolution of the FAA Visibility Measuring System.) The same computer hopefully would be able to compute SVR and/or TVR at some future date. Most of the minicomputers on the market are highly modular and can be upgraded easily to meet additional requirements.

We present below the characteristics of an SDC which has the features just mentioned and which incorporates standard computer software and hardware realized by several low-priced minicomputers available on the market today.

## PROPOSED SIGNAL DATA CONVERTER WITH SIMULTANEOUS READ-IN FROM SEVERAL TRANSMISSOMETERS

The SDC concept to be proposed accepts inputs from the multiple transmissometers simultaneously. The SDC can be conveniently discussed by dividing its operation into 3 separate phases. These are data input (input interface), computation (computer) and display drive (output interface).

### Input Interface

At the input interface, the SDC receives the data from the multiple sensors and other information related to the computation of the visibility. Nine inputs, carried by telephone lines from the nine transmissometers, will have relatively high repetition rates. For example, present transmissometer output

rates have upper limits of 4000 pulses per minute (ppm) corresponding to 99+% atmospheric transmission. In order to accommodate the possibility of higher pulse rates, we will consider the upper limit of any future device to be 12000 ppm (=200 pulses per second). Information on background illuminance, high intensity runway lights, baselines, etc., will require relatively little up-dating and can be introduced in the form of pulse trains whose frequencies are chosen conveniently.

Two distinct schemes for introducing the transmissometer data were considered. In the first scheme, each transmissometer is connected directly to a specific bit of the input-output (I/O) bus, forming at any instant a 9-bit binary number, with a "0" or "1" bit indicating the absence or presence of a pulse, respectively. The status of the I/O bus would be sampled at closely-spaced intervals. The sampling interval, determined by a clock, must be a fraction of the width of the transmissometer pulses so that no pulses would be missed. Each successive 9-bit number would be compared with the one immediately preceding it and when a "0" becomes a "1" on any bit, a counter corresponding to that bit position would be incremented by 1 on instruction from the computer. After a counting time (10-12 seconds), the computer would take the values of each counter for calculation of RVR, at the same time resetting the counters to zero.

This method requires two clocks: one to establish the sampling rate (approx. 20 hz) and the second to set the up-date interval. The main advantage of this scheme is that it lends itself readily to digital filtering methods for eliminating the effects of noise spikes and sampling errors. For each 0 to 1 bit change corresponding to the arrival of a pulse at the I/O bus, there must be a 1 to 0 change at the trailing edge of that same pulse. The latter must follow by a time equal to the (known) pulse width. On this basis noise can be discriminated against effectively.

The sophistication inherent in the program for the preceding scheme leads to the use of a considerable fraction of the capacity of a small computer. In addition it requires cycling times of approximately one microsecond. Observations by TSC personnel of the pulse trains emerging at the end of telephone lines at Logan Airport in Boston (Figs. 2&3) indicated that noise was not a serious problem. The measurements at Logan represent only one situation and should not be considered as typical of other installations.

The second input scheme is indicated in the block diagram shown in Figure 6. Each of the transmissometer lines is connected to a counter. Since the largest number of counts

possible for any one counter is 2400 (200 pps times 12 seconds), it is necessary to use 12-bit counters. As indicated in Figure 6, it is assumed that all input data, including background illuminance, etc., has been digitized before reaching the input to the SDC.

To provide some degree of noise rejection, noise-immune input logic modules (industrial grade) are commercially available. These devices, not shown in Figure 6, precede each counter and discriminate against false signals to the counters on the basis of current, voltage and time of arrival of the pulses.

The transmissometer pulse counters are not reset to zero at the beginning of a counting interval, but rather to values which represent the complements of the background count measured (over a 12-second interval) for each transmissometer-receiver, when the transmissometer lamp is turned off. These background counts, which will be monitored periodically in the same manner used at present, will be stored in the computer memory and added to the counter with a negative sign at the initiation of a counting cycle.

The approaches discussed above are only two of several possible schemes. Variations of either could be employed. For example, the sophisticated "fast scan" method could be modified to reduce the computer load by causing program interrupts only when the arrival of a pulse at the interface is sensed. This would eliminate the need for the closely-spaced sampling intervals.

The choice of one method of data input interfacing will depend on more detailed analysis of software and hardware available in the market.

The advantage of minicomputers is the great flexibility available by means of programming. Thus it appears that a 16-bit minicomputer, with 4K memory and 1  $\mu$ sec memory access time will be able to perform all the tasks up to the 3rd modification stage of the present FAA RVR system (see Fig. 4) and the majority of the tasks to satisfy the needs of the 4th modification. To fully satisfy the needs of the 4th modification, additional modules will have to be added to the signal data converter. It is impossible to define, at this time, the modules required since the computational needs for SVR and TVR are still not defined.

#### Signal Data Converter Computer

At the termination of a counting cycle, the computer scans the counter readings and places them in the corresponding bit

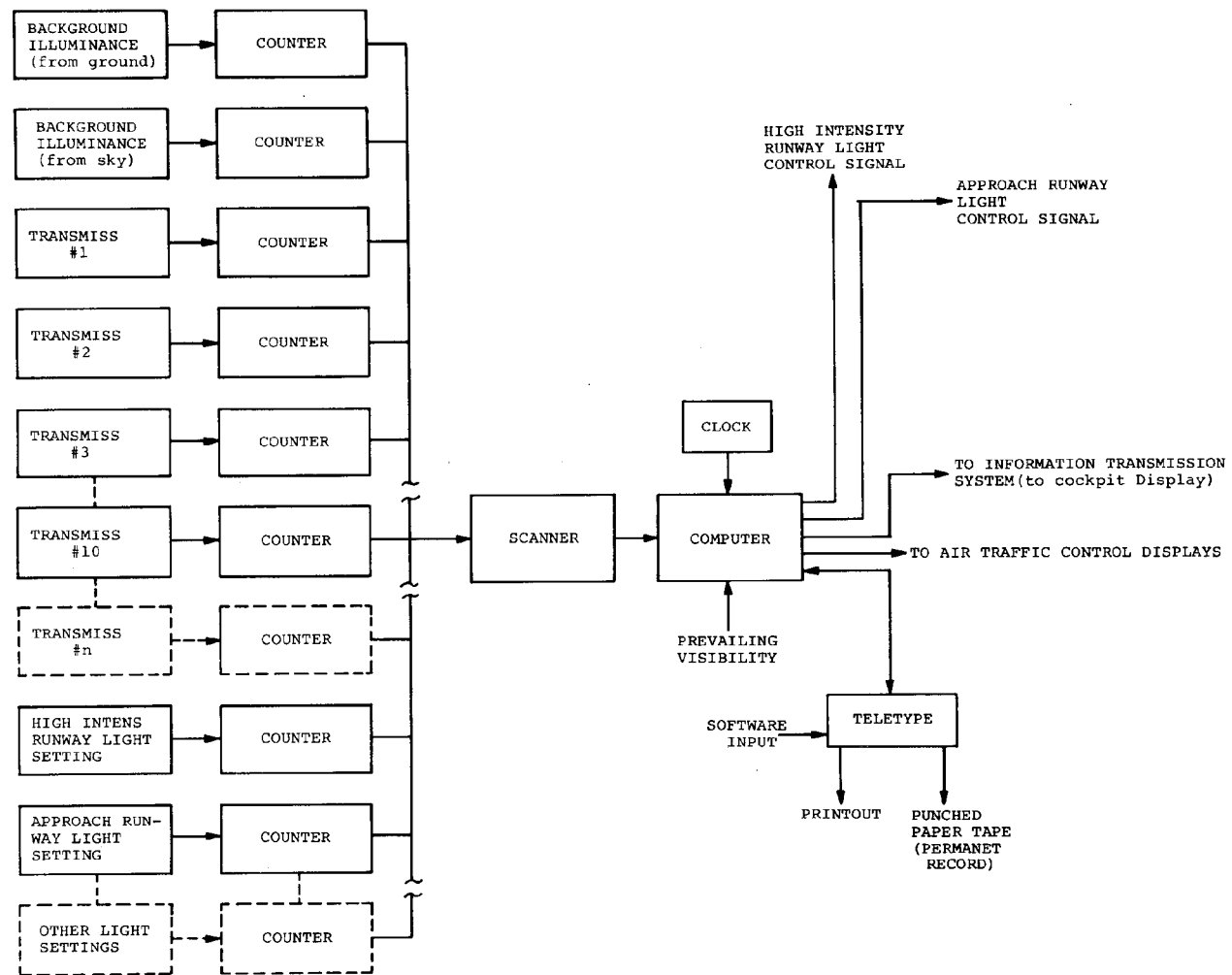
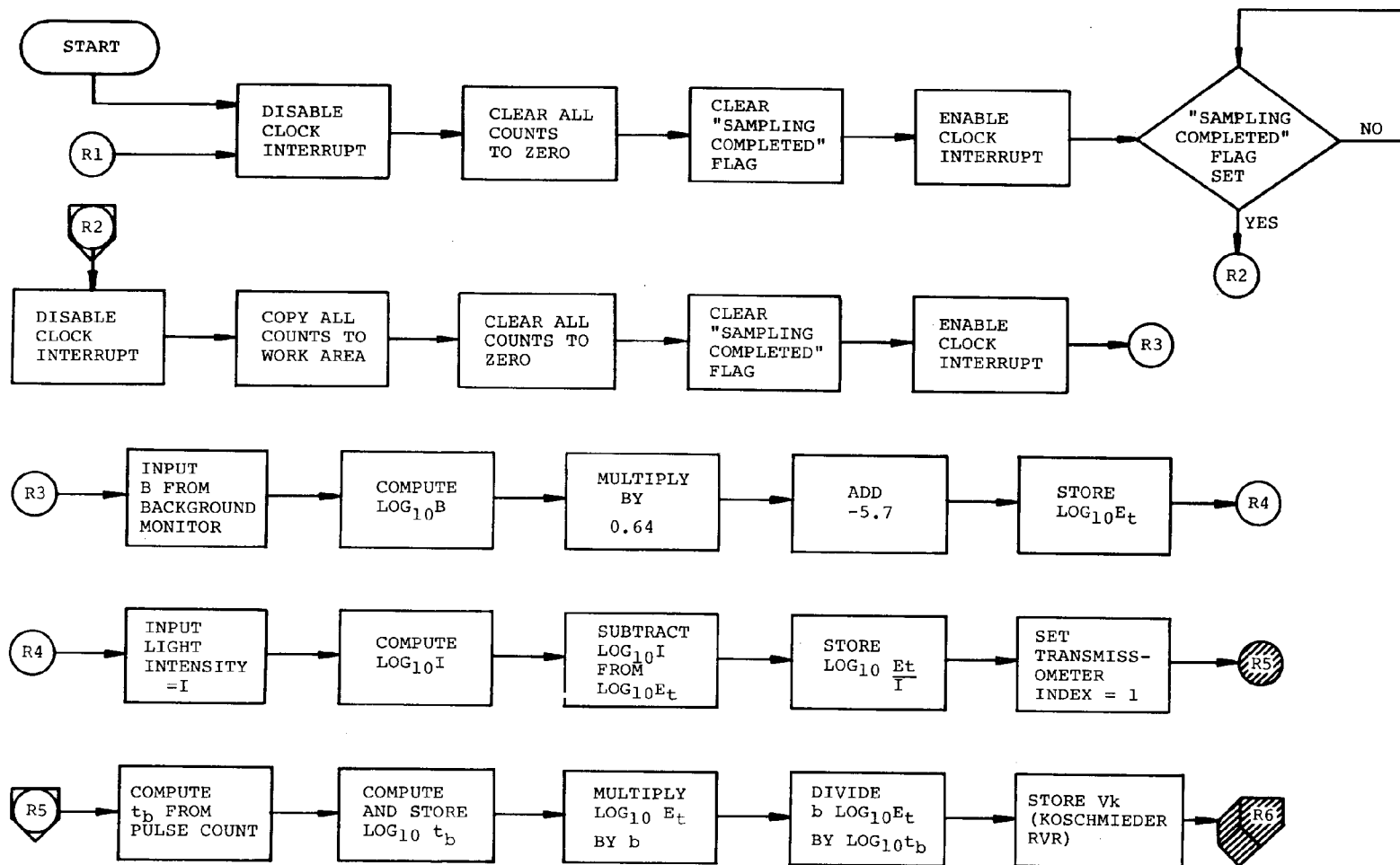


Figure 6. Block Diagram of a Signal Data Converter for a Multi-runway Visibility Measuring System.

positions of the accumulator or I/O bus. These values, along with the remaining, much more slowly varying inputs which have been discussed previously, are then entered into the algorithm for RVR and up-dated visibility values are computed as indicated in the flow chart of Figures 7a&b. The iterative solution to Allard's law is compared to the value resulting from the use of Koschmieder's law. Both laws are solved each time for each of the 9 sensors. Since visibility should not vary significantly between update intervals, the "starting" value for any interaction of V should be quite close to the final solution of the preceding interaction. The precision in RVR over all possible ranges is expected to be 1% or better after about 3 steps of iteration.

#### Output Interface

The output interface must be capable of translating a series of binary numbers into signals suitable for driving the visual displays. This output interface would very likely be packaged together with the input interface. For example, the Digital Equipment Corporation DR8-EA 12-channel Buffered Digital I/O combines the input and output functions in one module. Once the computer has computed the RVR, it can store these values and send them to the displays, using the interrupts from the clock as a basis. If and when other display devices requiring other signal patterns are developed, it will only be necessary to change this part of the program stored in the computer (and possibly some inexpensive circuitry to modify the output signal) to adapt to the new display.



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Figure 7a. Flow Chart of a Runway Visual Range Computer Program.



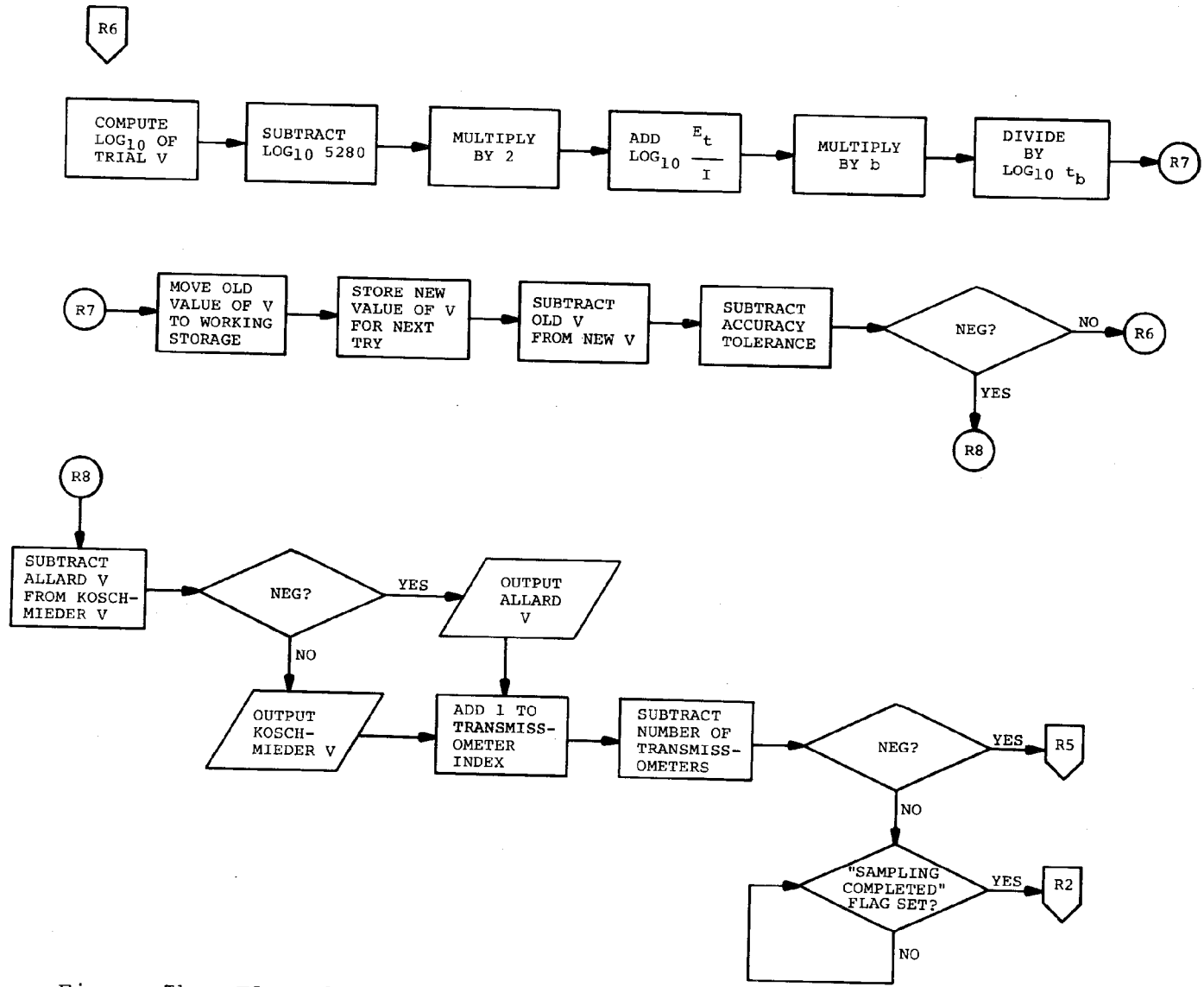


Figure 7b. Flow Chart of a Runway Visual Range Computer Program (Cont.)

## LIST OF REFERENCES

1. Douglas, C.A., Young, L.L., "Development of a Transmissometer for Determining Visual Range", National Bureaus of Standards, Report 47, February 1945.
2. "Preliminary Instruction Book, Runway Visual Range (RVR) System, Vol. I", July 1967, Prepared for the FAA, Contract FA6WA-1827 by Solid Radiations Inc., Los Angeles, California.
3. Ingrao, H.C., Lifnitz, J.R., "Proposed Control Tower and Cockpit Visibility Readouts Based on an Airport-Aircraft Information Flow System", Transportation Systems Center, Report No. DOT-TSC-FAA-71-18, July, 1971.
4. Lefkowitz, M., and Schlatter, "An Analysis of Runway Visual Range", Federal Aviation Agency, Report No. RD-66-100, December, 1966
5. Thomas, D.C., "Assessment of Visual Range on Runways", Journal of Science & Technology, 37,65 (1970)
6. AWOP Report IV-WP-213
7. Collis, R.T.H., Viezee, W. Uthe, E.E. and Oblanas. J., "Visibility Measurement for Aircraft Landing Operations", Stanford Research Institute, Report No. FAA No. DOT-FA 70WA1-178.