GAMMA SCIENTIFIC INCORPORATED / 3777 RUFFIN ROAD, SAN DIEGO, CALIFORNIA 92123 / (714) 279-8034

Description of Gamma Scientific Model 5000-14 Linearity Assembly

The Model 5000-14 Linearity Assembly is an attachment to the Model 5000 Optical Radiation Calibration System. It is an optical device which allows the measurement of a detector's amplitude response (linearity) relative to incident radiant flux. Its principle of operation involves the addition of two non-equal radiant fluxes. If the detector response is linear, the sum of the individual responses to each separate flux equals the combined response to both fluxes together. For example, if two fluxes (ϕ_1 & ϕ_2) are used to irradiate the detector, two responses (N_1 & N_2) are obtained. Now if both fluxes simultaneously irradiate the detector, a response N_{1+2} is generated. If the detector is linear, then $N_1 + N_2 = N_{1+2}$. If not, the nonlinearity may be expressed as the difference correction, K, to be applied to the detector's response as $K = N_1 + N_2 - N_{1+2}$.

This additive or superposition method of measuring linearity, because of its fundamental nature, has become the preferred technique by a number of national laboratories.

The optical system of the 5000-14 images a highly stable, DC powered, tungsten-halogen lamp filament into the 5000-11 Integrating Sphere. A series of apertures in the 5000-14 allow the different required flux levels to be generated. At any time either one of two apertures or both can be inserted in the flux path between the lamp and sphere. The apertures are mounted in a dual wheel configuration so that by rotating a single knob, various combinations of the apertures in these wheels can be introduced into the system. From the detector's responses to these combinations of apertures, the linearity correction factors can be calculated for the detector under test.

The range of measurement is 600:1 in fifteen nominally equal steps.

The instrument or detector to be calibrated is placed at the exit port of the sphere and rigidly held in place during the response measurements.

Narrow band, spectrally selective filters can be inserted in the 5000-9 Standard Lamp Baffle-Filter Assembly so that measurements of the detector's linearity may be made at various points throughout the optical radiation spectrum.

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Model 5000-14

The Model 5000-14 Linearity Assembly is a device which uses the principle of superposition of radiant energy to ascertain the linearity of detectors. It is designed to be used with the Model 5000 Optical Radiation Calibration System. The optics images the filament of the lamp onto either a cosine collector such as the 2020-13 or the entrance port of the 5000-11 Comparison Sphere. Apertures are placed sequentially between the optics, resulting in different irradiance levels at the image of the filament. The procedure is similar to that described in NBS special publication 378, pp. 63-70, a copy of which is included, together with a set of forms for recording the data obtained.

The 5000-14 is turned by a knob on the front face right side looking toward the baffle assembly from the direction of the lamphouse. It is mounted on a special dovetail end to the baffle assembly and is oriented so the long side is vertical. The knob is rotated counter-clockwise facing the 5000-14. A clutch prevents turning the knob in the opposite direction (it may be forced) so the data is taken in the proper order. If a data point is past and it is not desired to start over, the knob may be turned clockwise several steps (to avoid backlash) and the missed data recovered. This is <u>not</u> recommended for general procedure as it damages the clutch. If the operator is careful in turning the knob stopping at the detents, repetition is not necessary. It is also recommended that at least three complete cycles be read in determining the linearity of a detector in order to increase the precision. The linearity can thus be determined to 0.1% or better if care is used.

Data Reduction

The 5000-14 is started by rotating the knob to the position S for start. On the side of the assembly is a window through which letters are visible when the 5000 lamp is burning. Turning the knob CCW stopping for each letter (or combination) on the detent and recording the detector signal on the data sheets provided completes the data collection. The correction factors k_i for apertures i are then simply found by algebraic addition using the equations on the data collection sheet. A graphical plot of the correction factors as an example is included. Graphical smoothing or computer filling can also be performed, resulting in a plot or equation which yields corrected readings of the detector for any non-linearities.

INSTRUCTIONS FOR MOUNTING 5000-14 LINEARITY ASSEMBLY TO THE 5000-9 STANDARD LAMP BAFFLE ASSEMBLY

1. Remove exit port cover cap. The exit port is on the opposite side of the aperture control knob.

2. Hold the 5000-14 in left hand with thumb around entrance port and fingers holding the back side. Tilt the 5000-14 at about a 45 degree angle (the aperture control knob going away from you) and carefully slide onto 5000-9 entrance end. Slightly rotate back and forth until it slides all the way flush against the 5000-9.

3. Turn 5000-14 cw to a vertical position until it is vertical and straight.

4. Remove entrance cover cap.

5. Proceed with operating procedure.

6. The 5000-14 is for use only on the standard lamp end of bench with the 5000-9.

7. To remove, simply reverse the above procedure. REPLACE COVER AND CAPS WHEN NOT IN USE.

Rotter [8] analyzed the possibilities which existed for selecting and providing the irradiances to be measured in testing the nonlinearity of receptors by the superposition method. His treatment assumed that the irradiances were provided by a single stable source. A lens system with apertures graduated in size provided irradiances related in several different ways. Rotter analyzed the system with respect to the work involved and the accuracy produced.

He divided the measuring systems into two main classes:

1. Method in which more than two irradiances may be received at the same time.
   - 1.1. Method with, n, nearly equal sized openings, i.e., 1 : 1 : 1 : 1 : . . . .
   - 1.2. Method with gradation of the openings by a factor of two, i.e., 1 : 1 : 2 : 4 : 8 : 16 : 32 : . . . .
2. Method in which, at most, two irradiances are received at one time.
   - 2.1. Method with steps of pairs of equal irradiances increasing in size from one pair to the next by a factor of two, i.e., 1 : 1 : 2 : 2 : 4 : 4 : . . . .
   - 2.2. Method of increasing the size by steps of 62 percent which was first suggested and used by Rotter. These steps are arranged in size, according to the equation

$$A_i + A_{i+1} = A_{i+2}$$

except that the first two irradiances are equal in size, i.e., $A_0 = A_1 = 1$. The series then becomes 1:1:2:3:5:8:13:21:34:55:89:144.

For each method, Rotter gave the order of measurements, and the order of calculating the additive correction. As an example of this, the measurement program for Method 2.2 follows:

Reading	Irradiance	Correction
$N_{1'}$	1′	k_1
$N_{1',1}$	1′ 1	k_2
N_1	1	k_1
$N_{1,2}$	1 2	k_3
N_2	2	k_2
$N_{2,3}$	2 3	k_5

It is noted that each aperture is used in three consecutive readings, except aperture 1′, and the largest apertures are used only twice. The corrections k_i are found from

$$k_1 = 0 \qquad \text{(arbitrarily chosen)}$$

$$k_2 = N_{1'} + N_1 + 2k_1 - N_{1',1}$$

$$k_3 = N_1 + N_2 + k_1 + k_2 - N_{1,2}$$

$$k_5 = N_2 + N_3 + k_2 + k_3 - N_{2,3}$$

$$k_8 = N_3 + N_5 + k_3 + k_5 - N_{3,5}$$

The calculations to find the corrections, k_i, are thus easily determined by additions and subtractions in this method, whereas that presented by Sanders requires extensive mulplication.

Rotter's analysis showed that the Method 1.1 using n equal sized apertures was very expensive (in the number of measurements required) compared to the other three methods, if the range was greater than 1:4

Thus, for the range 1:8, Method 1.1 required twice as many readings. For the range 1:64, it required about ten times as many. However, Method 1.1 is more likely to be used with eight sources and will cover a range of 1:8. Then the source will be raised in intensity by a factor of eight to cover the next factor of eight on the scale. With this procedure, the equal sized aperture method would only require twice as many readings as the other three.

In Rotter's analysis of the errors in the corrections relative to the errors caused by the source variations, he found that Method 1.1 produced correction values with errors between two and three times lower than those produced by the other methods. Thus, at least four repetitions of the measurements in the last three methods would be required to produce measurements with the same error as those obtained by a single set of measurements by Method 1.1.

It thus seems that the choice of the best method must be made based on other criteria, such as cost of the equipment, ease of use, or minimization of drifts.

Rotter described three physical arrangements of

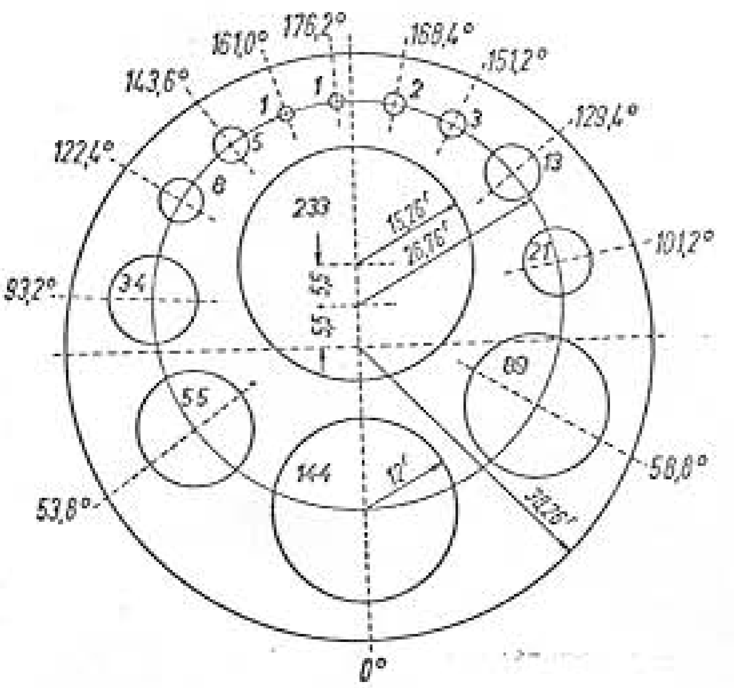


FIGURE 3. Rotter's aperture arrangement using 13 apertures with a sliding shutter on each. The angular position and relative diameter of each aperture is indicated. The outer circle indicates the outside diameter of the lens. (Courtesy, Messtechnik.)

apertures. One, reproduced in figure 3, has 13 apertures increasing in size by a factor of 62 percent, except for apertures 1 and 1′, which are equal. Each aperture is covered as required by a sliding shutter. The outer circle shows the size of the lens. This is a variation of Bischoff's [23] arrangement and makes good use of the lens area. The range covered is 1:377. The 13 sliding shutters make the method more complicated to use than that of Sanders or the one shown in figure 4 which was also given by Rotter.

This apparatus has two moving disks, B and C, with six apertures in each. The lens is outlined by the dotted circles enclosing both the smaller dotted circles D and E. These are apertures in a plate fixed in front of the lens. The numbers near the circles shown on the disks

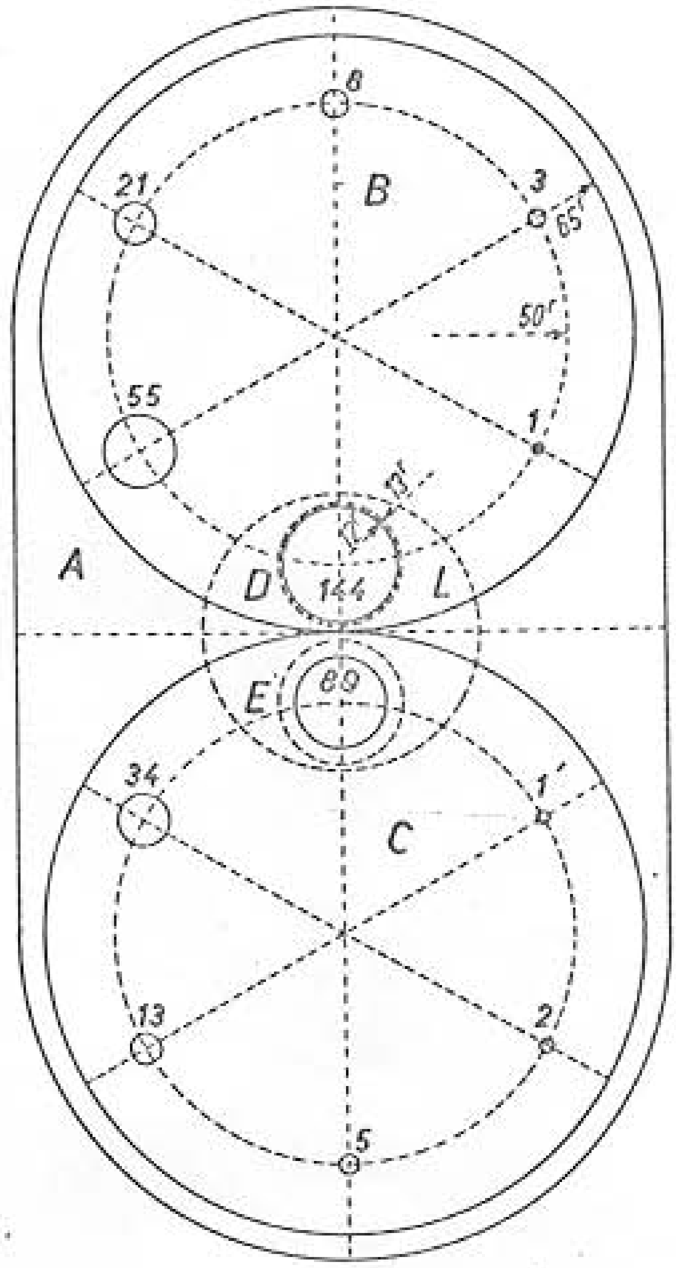


FIGURE 4. Rotter's aperture arrangement using two rotatable discs B and C with 6 apertures in each. Apertures D and E are in a disc before lens L with its outer diameter indicated by a dashed circle. (Courtesy, Messtechnik.)

indicate the relative area of these apertures. The disk B may be rotated to place any of the six apertures inside D or to cover D as required. The same applies to disk C relative to aperture E. The lens may be more effectively utilized if the holes D and E are oblong in shape and the largest holes in the disks are similarly distorted. This method of using two disks eliminates the requirement for a large number of moving parts. At the same time it requires less space and less accurate machining than Sanders linearity tester. Each disk remains stationary for three measurements as discussed above. The large disk in Sanders apparatus must be moved between the reading on A alone and the reading on A in combination with a. Thus there is a possibility of inexact reproduction of the flux through A or through a. Also, by using different disks in Rotter's apparatus, a different scaling of sizes may easily be selected. Also, disks B and C may be interchanged, which could be useful in eliminating certain errors.

EXAMPLE (ONE RUN)

5000-1A DATA REDUCTION SHEET

APERTURE	RD.	SUM	SUM			
A	12.3					
IA –	23.4	+ → +0.2	= +0.2	K_{IA}	@ IA	+0.85%
I	11.3					
IB –	36.1	+ → +0.2	+0.4	K_{IB}	@ IB	+1.1%
B	25.0					
JB –	62.5	+ → +0.0	+0.4	K_{JB}	@ JB	+0.64%
J	37.5					
JC –	101.8	+ → +0.1	+0.3	K_{JC}	@ JC	+0.29%
C	64.4					
KC –	168.3	+ → +0.0	+0.1	K_{KC}	@ KC	+0.06%
K	103.9					
KD –	273.0	+ → -1.1	-1.0	K_{KD}	@ KD	-0.36%
D	168.0					
LD –	442.0	+ → +0.0	-1.1	K_{LD}	@ LD	-0.24%
L	274.0					
LE –	715.5	+ → +0.5	-0.6	K_{LE}	@ LE	-0.08%
E	442.0					
ME –	1178.0	+ → +0.0	+0.5	K_{ME}	@ ME	+0.04%
M	736.0					
MF –	1920.0	+ → +2.0	+2.5	K_{MF}	@ MF	+0.13%
F	1186.0					
NF –	3110.0	+ → +6.0	+8.0	K_{NF}	@ NF	+0.26%
N	1930.					
NG –	5030.	+ → -10.0	-2.0	K_{NG}	@ NG	-0.039%
G	3090.					
OG –	8110.	+ → -10.0	-14.0	K_{OG}	@ OG	-0.17%
O	5010.					
OH –	12720.	+ → -50.0	-70.0	K_{OH}	@ OH	-0.55%
H	7660.					

NOTE EQUATIONS

$K_A = 0$

$K_{IA} = A + I - IA$

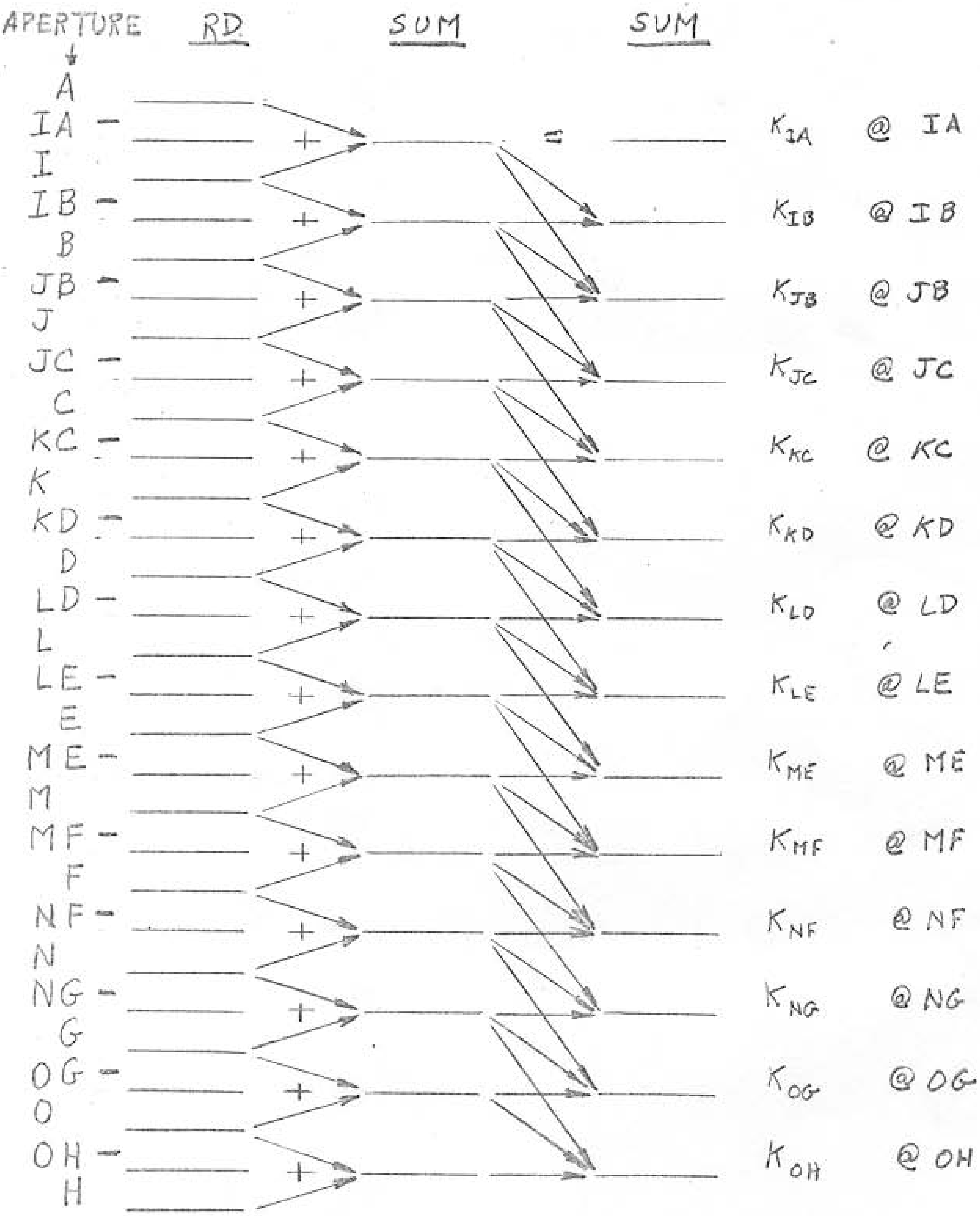
$K_{IB} = I + B - IB + K_{IA}$

$K_{JB} = B + J - JB + K_{IA} + K_{IB}$

etc.

543:1

5000-1A DATA REDUCTION SHEET



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