Graphical Solution for the Back Pressurization Method of Hermetic Test

STANLEY RUTHBERG

Abstract—The back pressurization method for leak-testing hermetically sealed electronic packages requires gas-flow modeling to relate indicated leakage rates to true leak size. The molecular flow relationship which is appropriate for fine leak sizes is nonlinear and requires a numerical solution, which in actual test application may involve either many trial calculations or the use of approximations that lead to limiting case values. A new graphical procedure is presented for complete solution of the molecular flow equation for any given test condition and package volume through the use of a single set of characteristic curves and a test line. The effects of repetitive testing and of prefill with tracer gas are also considered. The characteristic curves are appropriate for both the helium leak detector and the radioisotope methods of test, while the form of the test line distinguishes between the two methods.

I. INTRODUCTION

The back pressurization method for leak-testing hermetically sealed packages is accomplished by forcing a tracer gas into the package interior and then measuring the quantity of gas that has penetrated the leak channel. The two tracer gases most commonly used for semiconductor devices are helium and radioactive krypton. With helium as the tracer gas, measurement is made by extracting the gas back through the leak into the helium mass spectrometer leak detector; with radioisotope Kr85 as the tracer, an external gamma counter determines the activity of the internal gas. Neither technique gives the true leak rate value directly; rather, both require a knowledge of the gas transport mechanism and the use of appropriate mathematical models for the determination of test parameters. As the gas transport mechanism for leaks under pressurization is that of transition flow [1], which combines the elements of molecular and laminar viscous flow in a manner not amenable to direct analytical solution [2], a number of simplifying flow models have been used.

Traditionally the molecular flow approximation which is relevant for very fine leaks has been used to relate the helium leak detector indication to the leak size, but even here a transcendental relationship is obtained which is double-valued in leak size for each machine indication [3]. Thus numerical calculations are required to select pressurization parameters and to determine leak size. If precise values of leak size are required as in test evaluation or comparison, it is necessary either to use successive approximations or to construct a family of curves representing solutions for each parametric variation [4]. If an approximate correlation is sufficient, extensive tables of computer solutions for discrete values of parameters have been available [5]. Finally, if only approximate values for the minimum detectable leak size and/or the maximum detectable leak size are sufficient, as for screening purposes, graphs are available for a limited range of parametric values [6].

The radioisotope test method is usually modeled by the laminar viscous flow approximation [7] which is relevant in principle to the larger leak sizes. The assumption is made that the internal gas pressure remains small and increases linearly with time under pressurization. The loss of gas back through the leak is also neglected [8]. While such modeling leads to a simple relationship between gamma-ray count rate and leak size, correlation of the results between this method and the helium leak-detector method is obscured.

In this paper a graphical procedure is presented for complete solution of the molecular flow equation for any given test condition. Only a single set of characteristic curves is required along with the use of a test line. The selection of parametric values for pressurization, time of pressurization, and lapsed time to achieve a given leak-test range for any package volume is readily made, and the effect on test results due to variation in parameters is easily visualized. The procedure is applied to both the helium and the radioisotope methods, and a comparison of operational behavior is derived for the fine leak range for which molecular flow is appropriate. In addition the case of repetitive testing is considered. Either prior testing or a prefilled packages with tracer gas can affect test results considerably, yet this situation has not been approached previously on a formal basis. Correction of results is particularly appropriate for test evaluation and interlaboratory comparisons.

II. INTERNAL FRACTIONAL PARTIAL PRESSURE

A. Exact Solution

The gas transport into and out of a package due to a molecular flow leak is described by

\[ \frac{dP}{dt} = F(P_1 - P_2) \]  

(1)

where \( V \) is the internal free volume of the package available to gas collection, \( V \frac{dP}{dt} \) is the flow rate into (or out of) the package at ambient temperature, \( F \) is the molecular-flow conductance of the leak channel [9], and \( P_1 \) and \( P_2 \) are the partial pressure of the tracer gas at each end of the leak channel. By definition the standard leak rate \( L \) for a given gas is that flow rate obtained with 1 atm of gas pressure up-
stream to the leak channel and zero pressure downstream so that from (1)

$$L = \frac{rP_0}{P}$$

(2)

for $P_0$ equal to 1 atm \[10\]. It then follows from (1) and (2) that when a previously unexposed package has been immersed in a tracer gas at a pressure $P_E$ for a period $T$, the internal partial pressure $P$ is

$$P = P_E \left[1 - \exp \left(-\frac{L}{P_0V} T\right)\right].$$

When the pressurization ceases the tracer gas effuses back through the leak so that the interior tracer gas pressure decays exponentially. Then for any given elapsed or dwell time $t$

$$P = P_E \left[1 - \exp \left(-\frac{L}{P_0V} T\right)\right] \exp \left(-\frac{L}{P_0V} t\right).$$

(3)

If the interior partial pressure of the tracer gas is not zero but is initially $P'$ due to a previous test or to a prebill of the package, the resultant pressure is

$$P = \left[P' + \left(P_E - P'\right) \left[1 - \exp \left(-\frac{L}{P_0V} T\right)\right]\right] \cdot \exp \left(-\frac{L}{P_0V} t\right).$$

(4)

The pressure change within the package is thus determined by a time constant

$$\tau = \frac{P_0V}{L}$$

(5)

or the relaxation rate $R_\tau$ which is the reciprocal of the time constant

$$R_\tau = \frac{L}{P_0V}.$$  

(5a)

Now the bracketed expression in (3) is a measure of the relative increase in the internal gas concentration, and this value normalized by 1 atm pressure is defined here as the quantity

$$E = \frac{1}{P_0} \left[1 - \exp \left(-R_\tau T\right)\right] \exp \left(-R_\tau t\right)$$

(6)

which represents the internal fractional tracer gas pressure per atm of pressurization. This quantity $E$ will be used below to characterize the back pressurization method of hermetic test for both the helium leak detector and the radioisotope procedures.

A family of projections for $E$ as a function of the relaxation rate, with pressurization time and dwell time as parameters, is shown in Fig. 1 as derived from (6) for a range of parametric values sufficient for most semiconductor device packages; i.e., characteristics are included for a geometric series of values of pressurization time ranging from 0.1 to 300 h and values of dwell time ranging from 5 min to about 3 h. The initial and final segments for these curves can be obtained readily from limiting solutions for small leaks and for large leaks as follows.

**B. Fine Leak Approximation**

For relatively small values of $R_\tau$, from (6)

$$E \equiv \frac{R_\tau T}{P_0},$$

(7)

Therefore with $T$ as a parameter the $E$, $R_\tau$ characteristics are initially linear projections at a 45° slope on the log-log plane. A projection for any value of $T$ can be erected quickly by taking a coordinate point and passing a line of 45° slope through the point, i.e., by calculating $E$ for a given $R_\tau$ or an $R_\tau$ for a given $E$ with $T$ as a parameter in (7). The locations of lines of intermediate values of $T$ are indicated in the figure by tick marks for $T = 1$ to 10.

**C. Large Leak Approximation**

For relatively large values of $R_\tau$

$$E \approx \frac{1}{P_0} \exp \left(-R_\tau t\right),$$

or

$$R_\tau \approx -\frac{1}{\ln (P_0E)}.$$  

(8)

Thus the relaxation rate increases directly as the dwell time diminishes, the pressurization time is not a significant factor, and the relaxation rate changes little with large variation in $E$ for any given dwell time. This downslope segment for any $E(t)$ can be approximated readily by considering numerical values of $E$ of the form

$$E = \frac{1}{P_0} \times 10^{-n}$$

whence

$$R_\tau \approx \frac{2.303n}{t}$$

(9)

and by joining with a straight line segment two points calculated from (9) for the selected value of $t$ and two successive values of $n$ in the $R_\tau$ region of interest.

**III. HELIUM LEAK DETECTOR METHOD**

**A. Test Equations**

When the tracer gas is helium, the flow rate of helium from the package interior back through the leak conductance and
RELAXATION RATE, \( R_t [s^{-1}] \)

![Image](image.png)

Fig. 1. \( E \), the relative partial pressure of tracer gas within package interior free volume per atmosphere of external tracer gas pressurization, as function of relaxation rate \( R_r \) with pressurization time \( T \) and dwell time \( t \) as parameters. Transport mechanism is molecular flow.

into the helium leak detector will by (1) give rise to an indicated leak rate \( R \) given by

\[
R = F \cdot P
\]

where the pressure within the leak detector is much less than \( P \). Most tests for package leakage are done soon after assembly so that the initial interior helium concentration is zero. For such packages the leak detector indication is then from (2) and (3)

\[
R = P_E \cdot L \cdot E
\]

or from (5a)

\[
\frac{R}{P_0 V P_E} = R_r \cdot E.
\]

Thus the solution is characterized by the two factors \( E \) and \( R_r \), and all solutions relating leak detector response to standard leak rate may be derived from the characteristic projections for \( E \) along with an appropriately placed test line.

**B. Test Lines**

It is apparent from (11) that the locus of all solutions for any test sequence will lie on a line of 45° negative slope on the \( \log E \)-log \( R_r \) plane; for, with a given volume, indicated leak rate and pressurization the product \( R_r \cdot E \) is a constant. Fig. 2 includes test lines ranging from \( 1 \times 10^{-5} \) (atm * s)**-1** to \( 1 \times 10^{-10} \) (atm * s)**-1**. A test line for any other value can be constructed similarly as a line of 45° negative slope through a coordinate point represented by \( R_r \cdot E = \) constant.

Then specific solutions are defined by the intersection of the test line with that \( E(T, t) \) characteristic corresponding to the particular test values of \( T \) and \( t \). Solutions to all modes of test operation may be so obtained.

1) *Unknown Leak Size*: In one mode of operation it may be desired to determine the leak size of a specimen of internal volume \( V \) which has been subjected to an arbitrary set of back-pressurization parameters \( P_E \), \( T \), and \( t \) for which an indicated leak rate \( R \) was obtained. To solve this, the appropriate test line value is first computed from \( R/(P_0 \cdot V \cdot P_E) \). The intersection of this test line with the upslope portion \( E(T) \) of the curve corresponding to the given pressurization time and with the downslope portion \( E(t) \) corresponding to the given dwell time determine the two possible solutions for \( R_r \) from which the standard leak rate for helium \( L \) is determined. The leak size, which is defined as the standard leak rate for air, is \( L/2.69 \).

**Example**: Consider a volume of 0.1 cm³ pressurized to 5 atm abs (~60 psig) in pure helium for 2 h and then put on the helium leak detector 50 min later to give a reading of \( 5 \times 10^{-8} \) atm * cm³/s. The true leak size is required. The appropriate parameters follow.

\[
V = 0.1 \text{ cm}^3.
\]
\[
P_E = 5 \text{ atm} \cdot \text{abs}
\]
\[
T = 2 \text{ h}.
\]
\[
t = 3000 \text{ s}.
\]
\[
R = 5 \times 10^{-8} \text{ atm} \cdot \text{cm}^3/\text{s}.
\]

The steps are as follows.

a) Compute \( R_r \cdot E = R/(P_0 \cdot V \cdot P_E) = 1 \times 10^{-7} \) (atm * s)**-1**.

b) In Fig. 2 find the intersection of the \( 1 \times 10^{-7} \) (atm * s)**-1** test line with the \( T = 2 \text{ h} \) characteristic. Since \( T = 2 \text{ h} \) is not shown in Fig. 2, lay a scale parallel to

---

1. Although the SI system of metric units is now preferred, present engineering practice uses units of atm*cm³/s for leak rate and lbf/in² for pressures near or greater than 1 atm. Conversion factors are 1 Pa = \( 1.451 \times 10^{-4} \text{ lbf/in}^2 \), 1 Pa*cm³/s = 9.869 atm*cm³/s, and 1 atm = \( 1.01325 \times 10^5 \text{ Pa} \).

2. Leak rate for helium/leak rate for air = (molecular weight air/molecular weight helium)**1/2** = 2.69, where \( M_{\text{air}} = 28.98 \) [11].
the $R_\tau$, $E$ characteristics and through the 2-h tick mark.

Determine the value of $R_\tau$ at the intersection. $R_\tau \approx 3.6 \times 10^{-6}$ s$^{-1}$. Therefore by (5a) $L$ the standard leak rate for helium is $3.6 \times 10^{-7}$ atm $\cdot$ cm$^3$/s from which the leak size is $1.3 \times 10^{-7}$ atm $\cdot$ cm$^3$/s.

c) Follow the $1 \times 10^{-7}$ test line to the $t = 3000$ s $E(t)$ characteristic. Determine the value of $R_\tau$ at the intersect. $R_\tau = 2.8 \times 10^{-3}$ s$^{-1}$. Therefore $L = 2.8 \times 10^{-4}$ atm $\cdot$ cm$^3$/s and $L_{\text{air}} = 1 \times 10^{-4}$ atm $\cdot$ cm$^3$/s.

d) The leak size is either $1.3 \times 10^{-7}$ or $1 \times 10^{-4}$ atm $\cdot$ cm$^3$/s. Discrimination is made with a followup reading on the leak detector at a later time. Any significant change indicates that the leak rate is the larger value.

2) Pressurization Parameters: By far most hermetic test activity is for screening purposes. This requires a selection of parametric values so that all specimens with leak sizes greater than some specified value be rejected. The upper limit of the test is determined, however, by the shortest dwell time that can be obtained, and it is hoped the test range can be made broad enough to overlap that of the gross leak test that would follow.

First the reject level relaxation rate is calculated from (5a) from the package-free volume and the specified standard leak rate for helium, and a vertical line is erected on the chart at that value. The test line is calculated from the left side of (11) with the selected value of leak detector signal $R_\tau$, the package volume $V$, and a convenient pressurization value $P_E$.

The intersection of this test line with the $R_\tau$ line sets the choice for $T$. If the first test line selected produces an inconvenient value for $T$ one can move away from the first intersection to choose more satisfactory values for both $T$ and a test line. The only constraint is that the leak detector reject signal has to be greater than the minimum detectable signal by a suitable amount [12]. Then the corresponding maximum value of $R_\tau$ that can be detected is easily picked off by extending the test line to the $E(t)$ characteristic corresponding to the attainable dwell time. Alternatively the major factor in the test may be the maximum detectable leak size. Then the maximum value of $R_\tau$ is calculated and a vertical line extended from this value. The intersection with a suitable $E(t)$ characteristic determines the lower end of the test line which is then extended at a $-45^\circ$ slope to a suitable $E(T)$ characteristic.

**Example:** Consider an IC package of 0.01 cm$^3$ nominal free volume for which a reject leak size of $5 \times 10^{-8}$ atm $\cdot$ cm$^3$/s of air is required [8]. Suppose the background signal is found to be $1 \times 10^{-9}$ atm $\cdot$ cm$^3$/s of helium and a signal-to-background value of five is selected. Also the tests could be completed within 50 min after release from the pressurization chamber. Consider $P_E = 5$ atm $\cdot$ abs. The appropriate parameters follow:

\[
\begin{align*}
V &= 0.01 \text{ cm}^3, \\
L_{\text{air reject}} &= 5 \times 10^{-8} \text{ atm} \cdot \text{cm}^3/\text{s}, \\
R_{\text{reject}} &= 5 \times 10^{-9} \text{ atm} \cdot \text{cm}^3/\text{s (helium)}, \\
t &= 3000 \text{ s}, \\
P_E &= 5 \text{ atm} \cdot \text{abs}.
\end{align*}
\]

Then

\[
\begin{align*}
L &= 1.35 \times 10^{-7} \text{ atm} \cdot \text{cm}^3/\text{s}, \\
R_\tau &= 1.35 \times 10^{-5} \text{ s}^{-1}, \\
R_{\text{reject}} = P_E P_0 & \quad (1) = 1 \times 10^{-7} \text{ atm} \cdot \text{cm}^3/\text{s}.
\end{align*}
\]

The intersection of test line $1 \times 10^{-7}$ and $R_\tau$ of $1.35 \times 10^{-5}$ is at $T = 0.15$ h (see Fig. 3). But $T = 9$ min is too short for convenience. Consider $T = 0.3$ h instead. Doubling the value of $T$ at constant $R_\tau$ doubles $E$, as seen in (7), and hence the value of the test line; thus the detector reject level is increased to $1 \times 10^{-8}$ atm $\cdot$ cm$^3$/s. A $-45^\circ$ test line established at $T = 0.3$ h and $R_\tau = 1.35 \times 10^{-5}$ s$^{-1}$ ($R_\tau E = 2 \times 10^{-7}$) intersects the $t = 3000$ s characteristic at $R_\tau = 3.3 \times 10^{-3}$ so that the maximum standard leak rate for helium $L = 3.3 \times 10^{-5}$ atm $\cdot$ cm$^3$/s and then $L_{\text{air}} = 1.2 \times 10^{-5}$ atm $\cdot$ cm$^3$/s. However $1.2 \times 10^{-5}$ is borderline for any gross leak test, and the only way to increase the present limit significantly is to decrease the dwell time. Decreasing dwell time to the 1000-s ($\sim$17-min) characteristic would lead to an $R_\tau$ of $1.1 \times 10^{-2}$ and hence an $L_{\text{air}} \sim 4.1 \times 10^{-5}$ atm $\cdot$ cm$^3$/s for some improvement in overlap between the fine and gross leak test. Note that an increase in dwell time beyond $\sim$1 h would pull the intersection point off the straight line region of $E(T)$. It should also be noted that $P_E$ could be dropped to 2.5 atm pressure and the original value of leak detector reject limit of $5 \times 10^{-9}$ atm $\cdot$ cm$^3$/s be retained without changing the pressurization time test limits. Only the ratio of signal to background would be affected.

Since a leak size of $5 \times 10^{-8}$ atm $\cdot$ cm$^3$/s in a 0.01-cm$^3$ volume produces a time constant of only 2 days, consider a decrease in the reject leak size by a factor of 5 to give $1 \times 10^{-8}$ atm $\cdot$ cm$^3$/s. Then $R_\tau$ becomes $2.7 \times 10^{-6}$ s$^{-1}$ and the intersection of this value with the $2 \times 10^{-7}$ test line shows $T = 7.5$ h, a 25-fold increase in pressurization time; i.e., with (7) $R_\tau E \sim R_\tau^2 T/P_0$.

3) Repetitive Measurement: Often the package may include an initial partial pressure of helium because of prior testing or prefill, and this initial concentration will affect the test results. In practice specimens are conditioned in vacuum or allowed to stand for some time until an initial leak detector reading is relatively small, but when such a long wait time may not be suitable or where some accuracy is required a formal correction procedure is desirable.

The specimen is first placed in the inlet of the leak detector and an initial measurement is made of the effusion. The effusion rate $R_I$ is related to the interior partial pressure $P_I$ and to the standard leak rate through (2) and (10) as

\[
R_I = P_I \frac{I}{P_0}.
\]

After another delay period of $t''$, the specimen is subjected to hermetic test, and a final measurement is made. The initial partial pressure $P'$ just prior to pressurization, after further possible effusion during the delay, is

\[
P' = \frac{R_I P_0}{L} \cdot \exp \left(-R_\tau t'' \right).
\]
The measured leak rate $R_2$ obtained after pressurization is equal to $LP/P_0$ where $P$ is now described by (4). With (4), (6), and (12), it follows that

$$R_2 = R_1 \exp \left(-R_1 t''\right) \left[\exp \left(-R_1 t_2\right) - P_0 E_2\right]$$

$$+ P_0 V P E R_2$$

(13)

where the subscript 2 denotes the quantities related to the pressurization sequence. As a general approach, the solution is obtained by successive approximation as follows.

a) Compute an approximate test line value from

$$R_2 \approx R_1 \cdot E_2.$$ 

b) With this test line find the approximate values for $R_1$ and $E_2$ at $E(T_2, t_2)$, here designated as $R_1^* \text{ and } E_2^*$.  

c) Compute the value of $\exp \left(-R_1^* t_2\right)$ from the value of $t_2$ used in the test.

d) Compute the value of $\exp \left(-R_1^* t''\right)$ from the measured value of $t''$.

e) With these approximate values from b, c, d

$$\frac{R_2 - R_1 \exp \left(-R_1 t''\right) \left[\exp \left(-R_1 t_2\right) - P_0 E_2^*\right]}{P_0 V P E} \approx R_1 \cdot E_2.$$ 

(14)

This then is a corrected test line from which the two possible solutions may be obtained at the intersects for $E(T_2)$ and $E(t_2)$. Further iteration can be made.

If however the first approximated test line crosses the $E(T)$ characteristics in the region of straight line projections, then

$$\exp \left(-R_1 t''\right) \to 1$$

$$\exp \left(-R_1 t_2\right) \to 1$$

$$E_2' \approx 1,$$

so that by (14)

$$\frac{R_2 - R_1}{P_0 V P E} = R_1,$$

(15)

as one might expect.

At the large leak end of the test line, the solution is somewhat insensitive to variation in test line value since $R_1$ is primarily a function of $t_2$, i.e.,

$$\exp \left(-R_1 t''\right) < 1$$

$$\exp \left(-R_1 t_2\right) \to 0$$

$$E_2' < 1$$

so that

$$\frac{R_2}{P_0 V P E} \approx R_1 \cdot E_2,$$

(16)

and the prereading does not produce a significant correction.

Thus one only need see where the approximated test line falls to determine how much further iteration is required. If it falls in the fine leak area of straight line projections, simply take the difference between the final leak detector value and the prereading and calculate the test line value. The “true” value for $R_1$ is either at $E(T_2)$ or $E(t_2)$. If only the large leak value is desired, simply calculate the test line from $R_1$. If the approximated test line falls in the intermediate $R_1$ range, the iteration procedure is appropriate.

IV. RADIOISOTOPE METHOD

A. Test Equation

Since the ~0.5-MeV gamma radiation emitted by $Kr^{85}$ easily penetrates most semiconductor package walls the amount of pure $Kr^{85}$ that has passed through a leak channel and remains within the package cavity after pressurization in a $Kr^{85}-N_2$ gas mixture can be measured without resorting to extraction back through the leak channel as in the use of the helium leak detector. Thus the gamma count rate $R^*$ becomes

$$R^* = (PV) \cdot A \cdot K$$

(17)

where $P$ is the internal partial pressure of $Kr^{85}$, $PV$ is the quantity of $Kr^{85}$ at ambient temperature within the cavity,
$A$ is the activity of pure Kr$^{85}$ ($\mu$Ci/atm $\cdot$ cm$^3$)$^3$ and $K$ is the overall counting efficiency of the detector for the particular package type at a particular location within the crystal detector well (count rate/$\mu$Ci). The interior partial pressure is given by (3), but the external partial pressure $P_E$ is

$$P_E = \frac{S}{A} \cdot P_E^* \tag{18}$$

where $S$ is the specific activity of the Kr$^{85}$-N$_2$ gas mixture ($\mu$Ci/atm $\cdot$ cm$^3$) and $P_E^*$ is the pressurization value for the gas mixture. Thus

$$\frac{R^*}{P_0 \cdot V \cdot P_E^*} = SK \cdot E^* \tag{19}$$

where the solution is characterized only by the internal fractional partial pressure for Krypton $R^*$, here designated as $E^*$. 

1) Fine Leak Approximation: For relatively small values of relaxation rate with krypton $R^*$ by (7) and (19),

$$\frac{R^*}{P_0 \cdot V \cdot P_E^*} \approx \frac{R^* \cdot T^*}{P_0}$$

with $T^*$ denoting pressurization time with krypton. Thus

$$\frac{R^* \cdot P_0}{P_E^* \cdot SK \cdot T^*} = L^* \tag{20}$$

where $L^*$ is the standard leak rate for Kr$^{85}$. Package volume is not a factor, and (20) differs from the traditional recipe $[7], [8]$ in that $P_E^*$ is now raised only to the first power rather than to the second power as in the laminar viscous flow model.

B. Test Lines

For a given volume, indicated count rate, and pressurization in a particular gas mixture the locus of all solutions is now on a horizontal line of value $E^*$ rather than the 45$^\circ$ slope of the helium leak detector, and there is now no need to construct a set of such lines superimposed on the $E$, $R$, plane. Specific solutions for the test sequence are as before at the intersection of the test line with the $E(T, t)$ characteristic specified by the parametric values of $T$ and $t$.

1) Pressurization Parameters—Example: Consider again the 0.01-cm$^3$ package to be leak tested to $5 \times 10^{-8}$ atm $\cdot$ cm$^3$/s of air with a dwell time of 1000 s. Background count rates are generally of the order of 500 counts/min, a typical value for $S$ is 200 $\mu$Ci/atm $\cdot$ cm$^3$, and a typical value of $K$ is $10^4$ min$^{-1} \cdot \mu$Ci$^{-1}$. Assume a signal-to-background ratio of 5 for the reject level count rate and a 5-atm pressurization. It is desired to establish the required value of $T$ and the maximum detectable leak size $L_{air}$. The appropriate parameters follow.

3 Although the SI system of metric units is now preferred, present engineering practice uses units of curie for disintegration rate; 1 Ci = $3.7 \times 10^{10}$ Bq (events/s).

$V = 0.01$ cm$^3$

$L_{air}$ reject = $5 \times 10^{-8}$ atm $\cdot$ cm$^3$/s

$R_0^*$ = 500 min$^{-1}$

$R^*$ reject = 2500 min$^{-1}$

$S$ = 200 $\mu$Ci/atm $\cdot$ cm$^3$

$K$ = $10^4$ min$^{-1} \cdot \mu$Ci$^{-2}$,

$t^*$ = 1000 s.

Then with $(M_{air}/M_{Kr^{85}})^{1/2} = 1/1.71$, one obtains

$$L_{Kr^{85}} \text{ reject} = 5 \times 10^{-8} \left( \frac{M'}{M_{Kr}} \right)^{1/2} = 2.92 \times 10^{-8} \text{ atm} \cdot \text{cm}^3/\text{s}$$

whence

$$R^* = 2.92 \times 10^{-6} \text{ s}^{-1}$$

so

$$P_0 \cdot VP_E^* \cdot SK = E^* = 2.5 \times 10^{-2} \text{ atm}^{-1}$$

As shown in Fig. 4 a line is erected at $R^* = 2.94 \times 10^{-6}$ s$^{-1}$, and a horizontal test line is placed at $E^* = 2.5 \times 10^{-2}$. At the intersection with the $t = 1000$ s segment, $R^*_\text{max} = 5.88 \times 10^{-7}$ s$^{-1}$ such that $L_{air} = 6.5 \times 10^{-8}$ atm $\cdot$ cm$^3$/s. Note that leak rates are for Kr$^{85}$ and hence $R^*$ values are smaller than for helium for a given air leak.

Were the reject limit lowered to an $L_{air}$ of $1 \times 10^{-8}$ atm $\cdot$ cm$^3$/s, $R^*$ would be $5.88 \times 10^{-7}$ s$^{-1}$ so that $T$ is 11.8 h; that is, the pressurization time changes linearly with $R^*$, as evidenced in Fig. 4 and in (20) for the straight line projection region of $E(T)$.

2) Repetitive Measurement: An initial count rate made on the specimen relates to the quantity of Kr$^{85}$ already within by (17). After a lapsed time $t''$ the specimen is pressurized. The interior pressure just before this is equivalent to that expressed in (12) or

$$P' = \frac{R^*_1}{V \cdot A \cdot K} \exp \left(-\frac{R^*_1}{V \cdot A \cdot K} t''\right).$$

The final pressure after processing is as in (4), and the final count rate is again determined by (17) as

$$R^*_2 - R^*_1 \exp \left(-\frac{R^*_1}{V \cdot A \cdot K} t''\right) \left[\exp \left(-\frac{R^*_1}{V \cdot A \cdot K} t_2\right) - P_0 E_2^*\right]$$

$$= SK \cdot E_2^* \tag{21}$$

which is of the same form as (14). In the small leak range where $\exp \left(-\frac{R^*_1}{V \cdot A \cdot K} t''\right)$ and $\exp \left(-\frac{R^*_1}{V \cdot A \cdot K} t_2\right)$ are $\sim 1$, and as $E_2^* \ll 1$, the initial count rate is a direct correction or

$$\frac{R^*_2 - R^*_1}{P_0 V \cdot P_E^*} = SK \cdot E_2^*. \tag{22}$$
Fig. 4. Test line and example of test range for radioisotope method.

In the large leak range where \( \exp(-R_r \cdot t^*) \ll 1 \), \( \exp(-R_r \cdot t_2) \ll 1 \), and \( E_2 \ll 1 \), the prereading is not significant. In the intermediate range, \( \exp(-R_r \cdot t^*) \ll 1 \), \( \exp(-R_r \cdot t_2) \ll 1 \), and \( E_2 \ll 1 \), the prereading is not significant. In the inter- leak rates for a given leak size which is \( \frac{M_{He}}{M_{Kr}} \). For the helium method, the approximation of (7), and the detector outputs in terms of signal-to-background, for the same pressurization value, as

\[
\frac{n^* R_0^*}{R_0} = \frac{SK}{4.61 R_r} \cdot \frac{T^*}{T}
\]

where the ratio \( R_e^* \) to \( R_e \) is equal to the ratio of the standard leak rates for a given leak size which is \( \frac{M_{He}}{M_{Kr}} \) or \( \frac{1}{4.61} \). \( n \) is the signal-to-background ratio, and \( R_0 \) is the threshold signal.

A direct numerical comparison can be obtained for the fine leaks by using (19) for the radioisotope method, (11) for the helium method, the approximation of (7), and the detector outputs in terms of signal-to-background, for the same pressurization value, as

\[
\frac{n^* R_0^*}{R_0} = \frac{SK}{4.61 R_r} \cdot \frac{T^*}{T}
\]

where the ratio \( R_e^* \) to \( R_e \) is equal to the ratio of the standard leak rates for a given leak size which is \( \frac{M_{He}}{M_{Kr}} \) or \( \frac{1}{4.61} \). \( n \) is the signal-to-background ratio, and \( R_0 \) is the threshold signal.

A direct numerical comparison can be obtained for the fine leaks by using (19) for the radioisotope method, (11) for the helium method, the approximation of (7), and the detector outputs in terms of signal-to-background, for the same pressurization value, as

\[
\frac{n^* R_0^*}{R_0} = \frac{SK}{4.61 R_r} \cdot \frac{T^*}{T}
\]

where the ratio \( R_e^* \) to \( R_e \) is equal to the ratio of the standard leak rates for a given leak size which is \( \frac{M_{He}}{M_{Kr}} \) or \( \frac{1}{4.61} \). \( n \) is the signal-to-background ratio, and \( R_0 \) is the threshold signal.

A direct numerical comparison can be obtained for the fine leaks by using (19) for the radioisotope method, (11) for the helium method, the approximation of (7), and the detector outputs in terms of signal-to-background, for the same pressurization value, as

\[
\frac{n^* R_0^*}{R_0} = \frac{SK}{4.61 R_r} \cdot \frac{T^*}{T}
\]

where the ratio \( R_e^* \) to \( R_e \) is equal to the ratio of the standard leak rates for a given leak size which is \( \frac{M_{He}}{M_{Kr}} \) or \( \frac{1}{4.61} \). \( n \) is the signal-to-background ratio, and \( R_0 \) is the threshold signal.
of microcircuit seal testing,” Air Force Systems Command, Rome Air
testing of pressure—‘‘bombed’’ sealed enclosures,” Varian Vacuum
Division/NRC Operation, Newton Highlands, MA, Oct. 1, 1968
Electron Devices with a Helium Mass Spectrometer Leak Detector,
545–552.
sealed components utilizing radioactive gas,” Int. J. Appl.
[8] Method 1014.2-Seal, Military Standard 883B, in Test Methods and
from U.S. Naval Publications and Forms Center, 5801 Tabor Ave.,
Philadelphia, PA 19120.)
[10] Glossary of Terms Used in Vacuum Technology, Committee on
Standards, American Vacuum Society Inc. New York: Pergamon,
1958, Definitions No. 20 and 236.
[12] AVS Helium Mass Spectrometer Leak-Detector Calibration (2.1-
18) Method 1014.2 Seal, Military Standard 883B, in Test Methods and
from U.S. Naval Publications and Forms Center, 5801 Tabor Ave.,
Philadelphia, PA 19120.)
sealed components utilizing radioactive gas,” Int. J. Appl.

High Density Multiwire Circuits Using Thinner Wires
ETSUJI SUGITA, OSAMU IBARAGI, AND SHIGEHARU MOMOI

Abstract—High density Multiwire circuit technology which can lay
two insulated wires between throughholes on 2.5 mm centers has been
developed. To reduce crosstalk smaller diameter wires were adopted
instead of conventional 0.16 mm diameter wires. Wire breakage and
improper wire tacking. A newly developed tackless wiring technique
backplane wiring boards in an electronic switching system.

I. INTRODUCTION

The main differences between Multiwire® circuits [1] and
printed circuits are that in Multiwire circuits a) insulated
wires are embedded into the adhesives by a numerically
controlled machine and b) cross-section of a wire is directly
connected to a plated throughhole. Therefore Multiwire tech-
nology simplifies wiring design while maintaining the possi-
bility of high interconnection density. Due to these features
Multiwire technology has attracted attention as an alternative
to the traditional multilayer printed circuits [2] or Wire-

Conventional Multiwire circuits have employed 0.16 mm
diameter wires and have permitted only one wire between
throughholes on 2.5 mm centers. In the application to back-
plane wiring it is necessary to improve the ability for wire
accommodation. High density wiring will be effective for achieve-
ment of this capability. However if two 0.16 mm wires are
laid, many wiring mistakes will occur and crosstalk will in-
crease. To solve these problems high density wiring using
thinner wires was studied.

This paper describes the crosstalk problem, a new wiring
 technique for high density Multiwire circuits, and backplane
wiring boards produced by high density Multiwire technology.

II. CROSSTALK

Although crosstalk measurements on multilayer printed
circuits are reported by [4] etc., measurements on high den-
sity Multiwire circuits have not yet been reported. In the
following paper crosstalk is described, and the effectiveness
of thinner wires in reducing crosstalk is shown.

Crosstalk equations for pulsed signals between parallel and
matched microstrip lines are given by (4) and (5).

$$V_N = \frac{1 + \alpha}{4} \cdot \frac{L_m}{L} \cdot V_D, \quad t_r \leq 2t_l$$

$$V_F = \frac{1 - \alpha}{4} \cdot \frac{L_m}{L} \cdot \frac{2t_l}{t_r} \cdot V_D, \quad t_r > 2t_l$$

where $V_N$ is near-end crosstalk voltage, $V_F$ is far-end crosstalk
voltage, $V_D$ is drive voltage, $t_l$ is propagation delay, $l$ is parallel
length, $t_r$ is rise time, $\alpha$ is $(C_m/C_l)(L_m/L_l)$, $C_m$ is mutual ca-
citance/unit length, $C_l$ is self-capacitance/unit length, $L_m$ is mutual inductance/unit length, and $L$ is self-inductance/unit length.

As Multiwire circuits have the structure shown in Fig. 1,
their $L_m$ and $L$ are given by the following forms [6], respec-
tively.

$$L = \mu \ln \frac{2h}{a}$$

$\mu$ is the permeability of the medium, $2h$ is the height
of the wire, and $a$ is the radius of the wire.