DESIGN STANDARD

WIRE DERATING

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Japan Aerospace Exploration Agency

This is an English translation of JREG-2-212. Whenever there is anything ambiguous in this document, the original document (the Japanese version) shall be used to clarify the intent of the requirement.

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Contents

1. Scope of Application

This standard provides the recommended current values for Raychem®55 wire, which is widely used in spacecraft, including for the wiring within components.
Wires exposed to the external environment outside the spacecraft must be designed with consideration given to the effects exerted by the space environment, such as temperature, radiation, atomic oxygen, and ultraviolet rays, and the recommended allowable current values defined in this standard may not be appropriate. Therefore, please note that, for wires exposed to the external space environment, detailed consideration of operating conditions - such as the mission profile of the spacecraft – are required. Appendix I in Section 6 describes the effects of space environment factors that should be considered.

2. Related Documents

2.1 Applicable documents

Within the scope defined herein, the following documents constitute part of this standard. If a conflict occurs between this standard and the applicable documents, the specifications in this standard take precedence.

(1) MIL-STD-975
NASA Standard Electrical, Electronic, and Electromechanical (EEE) Parts List

(2) NASA/TP 2003 212242
EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Derating

2.2 Reference Documents

The following are reference documents relating to this design standard:

(1) ECSS-Q-60-11A
Space product assurance Derating and end-of-life parameter drifts - EEE components

(2) ASTM E595
Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment

3. Definition of Terms and Abbreviations

3.1 Definition of Terms

(1) Single jacket wire

A wire insulated with one layer of insulation sheath.

(2) Twisted double jacket wire

A wire consisting of one layer of insulation sheath covering insulated twisted-pair wires that are further covered with one layer of insulation.

3.2 Abbreviations

AWG	American Wire Gauge	Standard for wires in the USA
ETFE	Ethylene TetraFluoroEthylene	Copolymerized ethylene tetrafluoride and ethylene
MLI	Multi Layer Insulator	Insulator consisting of multiple layers
SLI	Single Layer Insulator	Insulator consisting of a single layer

4. General Requirements

In general, the rated current of a wire is required in order that the wire be used at or below its rated temperature, this temperature being determined by the insulation used. The rated temperature for the Raychem®55 wire considered in this standard (silver-plated wire with electron beam crosslinked ETFE - i.e. copolymerized ethylene tetrafluoride and ethylene - sheath material) is 200°C (the rated temperature for tinned wire is 150°C). However, this represents only the guaranteed temperature for the unit and, since there is a failure mode in which the sheath adheres at 200°C or lower, the wire should be used at or below 150°C.

This standard defines the wire derating of the Raychem®55 wire under standard usage conditions. When using other wire materials, and for usage beyond the conditions of this standard, the following must be considered individually for each project:

(1) Performance of detailed thermal analysis on a wire harness (including bundled wires) using large currents and a study of the resulting effects.

(2) In the case of wires being bundled, specification of an appropriate current value for a single wire and for the relevant number of bundled wires, giving consideration to heat generation.

5. Requirements

5.1 Applicable Temperature

The maximum temperature of the wire must not exceed 150°C.
However, the above need not be applied if, even though the maximum temperature exceeds 150°C, it is proved that the wire sheath will not crack during the mission period.
In addition, the effect of temperature on the connectors and components in the vicinity of the wire must be considered.

5.2 Recommended Current

5.2.1 Maximum Current for Single Line

This standard adopts the requirements of MIL-STD-975 APPENDIX A 3.16, which is widely used to date, and the requirements of NASA Instruction EEE-INST-002 SECTION W1, use of which has begun recently (for single wire, the current values in both standards are the same). Table 5.2-1 shows the recommended maximum currents for a single wire. These values are for a thermal vacuum environment with an ambient temperature of 70°C.

Table 5.2-1 Recommended maximum current for single line

Wire diameter AWG	30	28	26	24	22	20	18	16	14	12	10	8	6	4
Current (A)	1.3	1.8	2.5	3.3	4.5	6.5	9.2	13	19	25	33	44	60	81

5.2.2 Recommended Current for Bundled Lines

Figures 5.2-1 and 5.2-2 show derating against maximum currents in a single line, with the number of bundled power line wires (i.e. the number of power lines only in the case of mixed power and signal lines) as the parameter. (For reference, the requirements of the conventionally adopted MIL-STD-975 are shown in the figure.) These diagrams must be used to verified that the current in the power lines is appropriate with regard to the configuration of the designed parts (ratio between power lines and signal lines, insulation material), and operating temperatures. (The upper and lower graphs shown in Figures 5.2-1 and 5.2-2 show the same data using different scales. Either figure may be used, according to convenience.) The points in the diagrams indicate the derating found in the test. Although it is possible to read interpolation values on the basis of the

graph, derating cannot be determined simply by linear extrapolation. Appropriate assessment is necessary in the case of bundled lines requiring extrapolation.
With respect to electromagnetic interference, it is desirable to separate power lines from signal lines. However, if this is not possible, the heating power lines should be considered as being at the center of the bundled lines for purposes of thermal design (practical implementation design) since this represents the worst situation. Figures 5.2-1 and 5.2-2 show derating under such conditions.

In the figures, power line +SLI and power line +MLI were tested in a configuration in which the power line was coated with insulation material. It must be noted that although this configuration suppresses external heat radiation, it also requires that large derating be considered.
The figures are based on assessment test data from the Japan Aerospace Exploration Agency. Excerpts of the supporting data are shown in Appendix II in Section 6.

5.2.3 Types of Power Lines

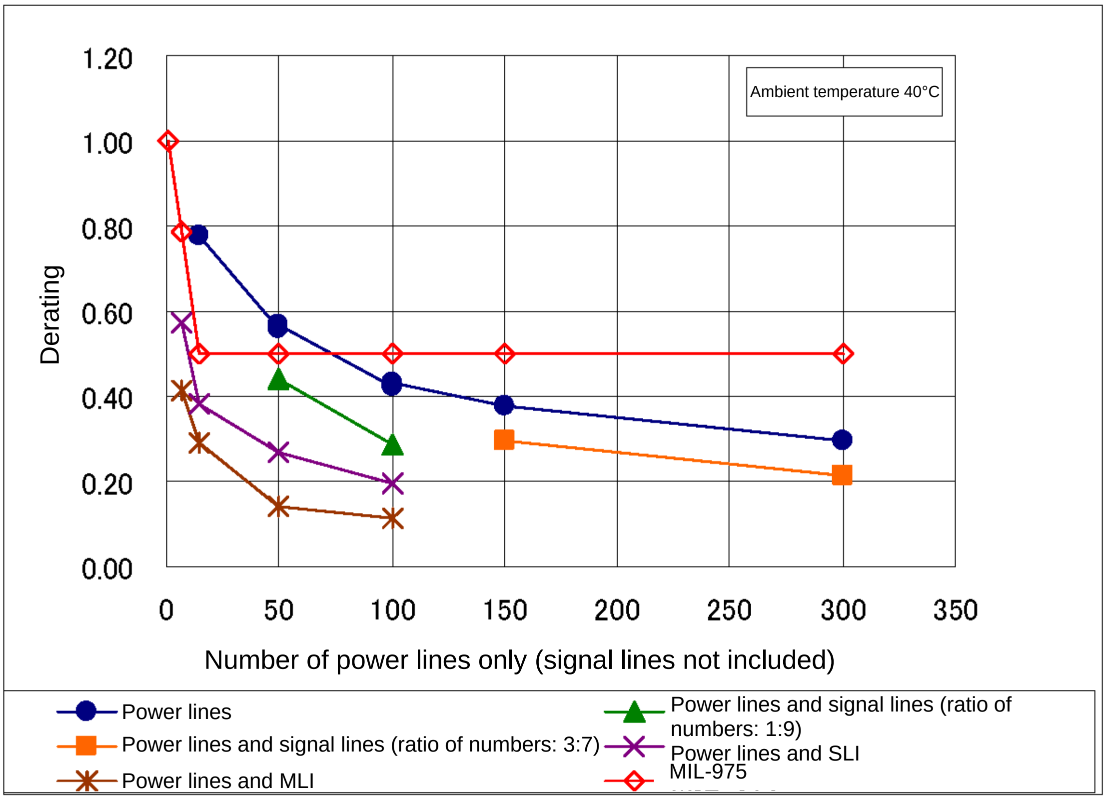
Single jacket wire and twisted double jacket wire were used for assessment, these being the types usually used in power lines, and it was verified that there were no significant differences between them. Accordingly, single jacket or twisted double jacket wire must be used when applying this standard. Additional assessment is required if other types of wire are used.

5.2.4 Wire Numbers of Power Lines

AWG20 wire was employed in testing, this being the most frequently used. However, the data presented here is also applicable to wires thinner than AWG14, in accordance with MIL-STD-975 specifying no difference in derating depending on wire thickness, and ECSS-Q-60-11A specifying no difference between AWG14 and thinner wires (although it gives a different specification for AWG12 and thicker).

5.2.5 Consideration of Case in which Different Wire Numbers are Mixed

If different wire numbers are used together, derating should be determined with the total number of lines to be bundled into power lines regarded as the number of bundles, and the allowable currents for each wire number should be found on the basis of the maximum current in a single line (Table 5.2-1).



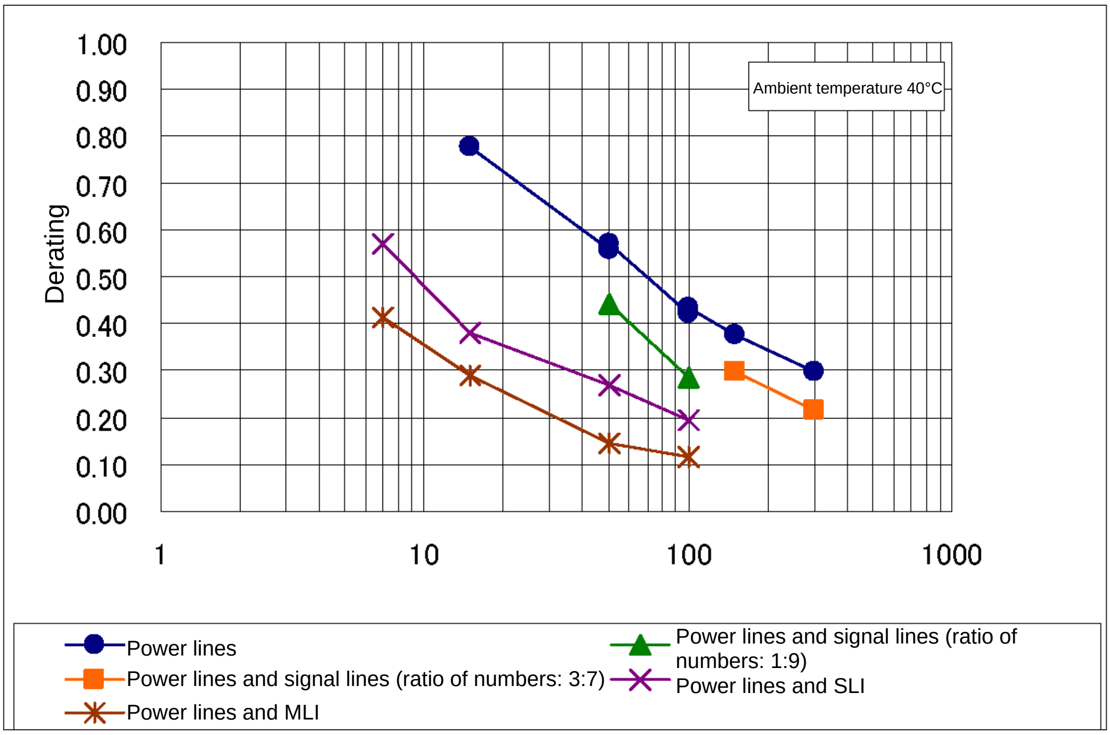
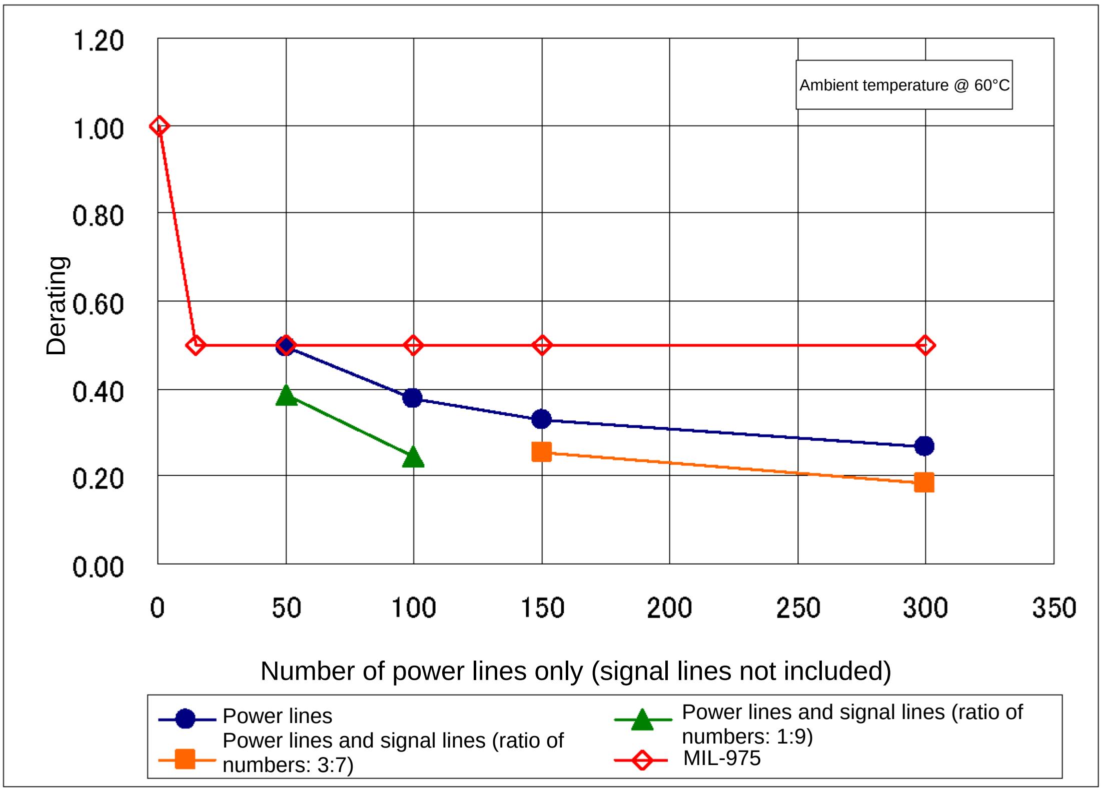


Figure 5.2-1 Derating of maximum current in single line with number of wire bundles as parameter (ambient temperature: 40°C)

Note: To find the maximum current value for a bundled line, use the value of maximum current for a single line shown in Section 5.2.1.



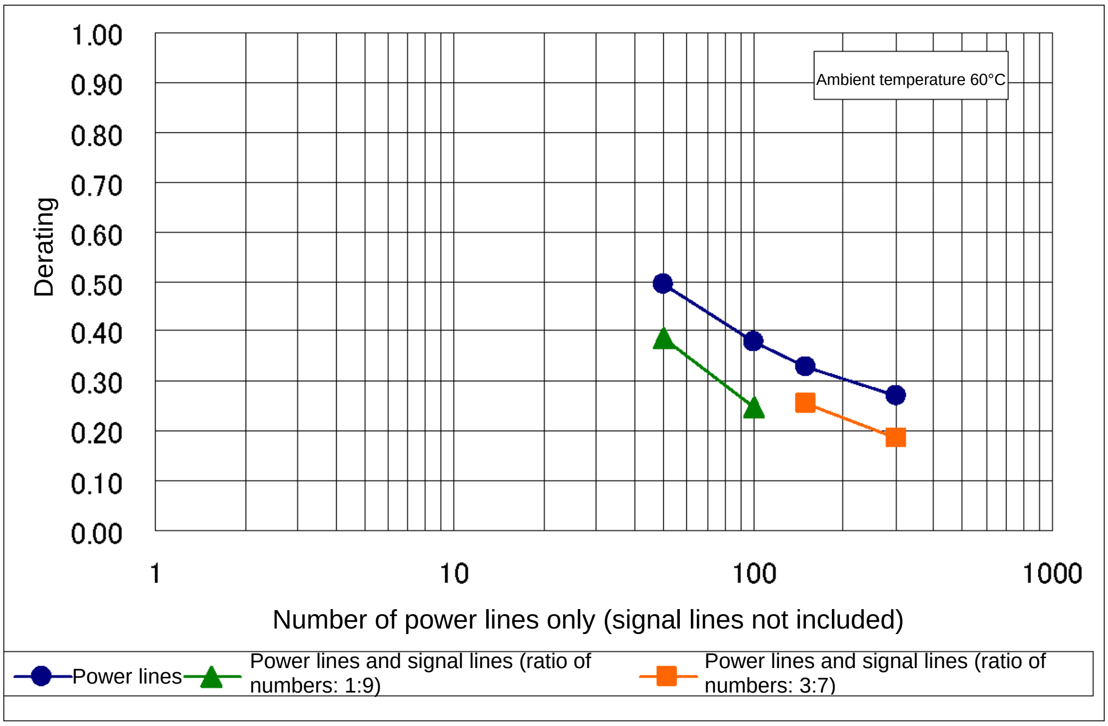


Figure 5.2-2 Derating of maximum current in single line with number of wire bundles as parameter (ambient temperature: 60°C)

Note: To find the maximum current value for a bundled line, use the value of maximum current for a single line shown in Section 5.2.1.

5.3 Maximum Current giving Consideration to Duty

In consideration of duty, if the peak current to be employed exceeds the maximum current given in Section 5.2, it must be proved by test or analysis that the requirements given in Section 5.1 are satisfied at the peak current wire temperature.

The maximum current in Section 5.2 is specified for constant current flow. For a pulse operated device, it is possible to control temperatures to below the specified level even though the maximum connected current is higher than the value shown in the previous section. However, it must be noted that, depending on the thermal capacity of the wire acting as heating element and on the duty factor, the temperature indicated in the previous section may be exceeded even at a low current levels. (For example, if the thermal capacity is low and there is a long continuous energizing period, a peak current flow twice the level shown in the previous section would not be acceptable at a duty of 25%.)

5.4 Measures in the Event of Nonconformity to the Recommended Values

The recommended values indicated in this standard are not necessarily applicable to all types of implementation. They have, with a view to generalization, been determined on the basis of assessment test results conducted under conditions in which the ends of the line material were thermally insulated. Hence, the validity of designing in accordance with the current values in this standard should be checked and, in cases of non-conformity, it must be proved that the relevant harness designs present no thermal problems by setting up thermal models of the corresponding parts.

5.5 When Use at Even Lower Temperatures is Desired

The recommended values indicated in this standard specify derating which satisfies the applicable temperatures given in Section 5.1. For use at even lower temperatures, refer to Section 6 Appendix II.

6. Appendix

In order to prepare this design standard, various tests were conducted on Raychem®55 wire. The main information obtained from these tests is given in this Appendix.

Appendix I Material Property Tests

1. Applicable Temperatures

The recommended values specified in this standard are based on the results of assessment tests conducted on Raychem®55 wire for use in space (this product has a long record of proven performance in space). Raychem®55 is an electron beam crosslinked ETFE wire. Although it has rated temperature of 200°C (the temperature at which it maintains an elongation of 50% under a temperature load of 10,000 hours), this is not a guaranteed value when implementation conditions and thermal cycles are considered. The following gives information obtained from the results of assessment tests which assume standard use in spacecraft. If lines of the same material are bundled and reach a temperature exceeding 160°C due to heat generation, the sheaths adhere to each other and the lines form a cluster even after unbundling.

- If lines of the same material are bundled and left in conditions under which line temperature reaches 150°C due to heat generation, unbundling causes the lines to separate from each other, although slight adherence exists between sheathes.
- According to the results of TG/DTA analysis on the sheath, a minute change in physical properties is detected at around 100°C.
- The crystalline melting point is approximately 236°C. Hence, the rated temperature of 200°C is assumed to have been specified in consideration of the crystalline melting point.
- Testing of the sheath material conducted using DMA (Dynamic Mechanical Analysis) showed slight expansion in the circumferential direction when temperature exceeded a point around 160°C, and sudden shrinkage (with rising temperature) was observed at around the crystalline melting point. In contrast, in the longitudinal direction the sheath material suddenly expanded at around the crystalline melting point. In the heating cycle up to 150°C, slight expansion caused by heating was observed, representing deformation within the scope of elasticity of the sheath material and leading to only a low mechanical load. The rated temperature of general ETFE (non-crosslinked) is 150°C. This value was therefore specified as the recommended temperature. 1)

2. Effects of Space Environment Factors

Raychem®55 wire sheath material for use in space is subject to the effects exerted by space environments, such as degradation of thermo-optic properties due to ultraviolet rays (increasing absorptance of sunlight), decrease in elongation due to electron beams, and corrosion by atomic oxygen - as shown below. In addition, the multiplicative effects that occur in these complex environments are not well understood. Shielding with thermal control materials is recommended to avoid direct exposure to the space environment.

(1) Ultraviolet rays

Ultraviolet rays have an effect on the material that reaches as far as the rays penetrate. (This depends on absorption of the ultraviolet rays by the material.) In addition to direct reaction to irradiation with ultraviolet rays, active substances created by the rays can affect the surroundings.

Raychem®55 wire sheath material for use in space shows a clear increase in sunlight absorptance resulting from irradiation with ultraviolet rays. The effect becomes pronounced as the temperature of the specimen rises. No change in infrared ray emissivity is observed.

In order to make an assessment of their effect on mechanical properties, ultraviolet rays were introduced up to 100ESD at room temperature. No decrease in the elongation of the sample was seen after irradiation with ultraviolet rays only as compared with a test sample before irradiation. When an environmental load of electron beams, heating, and ultraviolet rays - in that order - was applied, greater elongation occurred than when only electron beams then heating were applied. Degradation due to ultraviolet rays is concentrated on surfaces. Other parts, where the degradation is less significant, are dominant in the determination of mechanical properties, and this is believed to be the reason that no changes appeared.

(2) Electron beam

Raychem®55 wire sheath material for use in space has improved mechanical properties as a result of cross-linking by an electron beam. However, as the absorbed dose increases, not only cross-linking but also the ratio of cut chains increases, and this leads to degradation in mechanical strength.

NASA's cable selection guide describes it as “More resistant to radiation effects” (to 5 x 107 RADS → 500 kGy).

JAXA conducted tests using irradiation with an electron beam of 25 to 200kGy followed by exposure to a 190°C thermal vacuum for 7 days, and observed changes in elongation. The 150% elongation of a test sample before irradiation changed to approximately 60% after irradiation at 200kGy. This value does not necessarily indicate that elongation will cause an immediate break. However, it is desirable to use sheath materials within their scope of elasticity in consideration of expansion and shrinkage during thermal cycles.

The surface of the sheath material showed clear browning after irradiation by an electron beam of 1430kGy at a specimen temperature of 230°C. However, lower irradiation at room temperature showed only slight discoloration.

(3) Atomic oxygen

Irradiation testing with atomic oxygen showed a reaction efficiency of 1.7×10-24 (cm3/atom, the volume lost per oxygen atom). This value is closer to those for polyimide (1.5~3.0 ×10-24) and polyethylene (3.3~3.7 ×10-24) than those for many fluororesins, which are 0.1×10-24 or lower. Hence, the kind of resistance against atomic oxygen that is exhibited by fluororesins cannot be expected.

If the material is to be exposed to a low-orbit environment with a high volume of atomic oxygen, the decrease in material thickness (which affects both electric and mechanical properties) resulting from atomic oxygen must be taken into consideration.

(4) Outgassing

ASTM E595 outgassing property measurement results are as follows:

Total Mass Loss (TML): 0.098%

Collected Volatile Condensable Materials (CVCM): 0.002%

Water Vapor Regained (WVR): 0.025%

The data shows the properties of materials for use in space.

Appendix II Derating Acquisition Test

Appendix II shows excerpts of data from tests conducted in order to determine derating. The derating shown in Section 5.2.2 is specified based on this test data, and on the current value at which the central temperature reaches 120°C. 120°C was specified on the grounds of test error (maximum 20°C) and unpredictable errors (maximum 10°C) resulting from actual harness installation.

Figures II-1 to 4 show the results of the Derating Acquisition Test, and Table II-1 summarizes the test conditions.

In addition, Figure II-5 shows a comparison of the results obtained through the derating acquisition tests by difference in ambient temperature, and Figure II-6 shows a comparison by difference in signal line ratio.

Table II-1 Derating Acquisition Test Conditions

Figure	Specimen	Ambient temperature
Figure II-1	Bundle of power lines only	40°C
Figure II-2	Bundle of power lines only	60°C
Figure II-3	Mixed bundle of power lines and signal lines	40°C
Figure II-4	Mixed bundle of power lines and signal lines	60°C

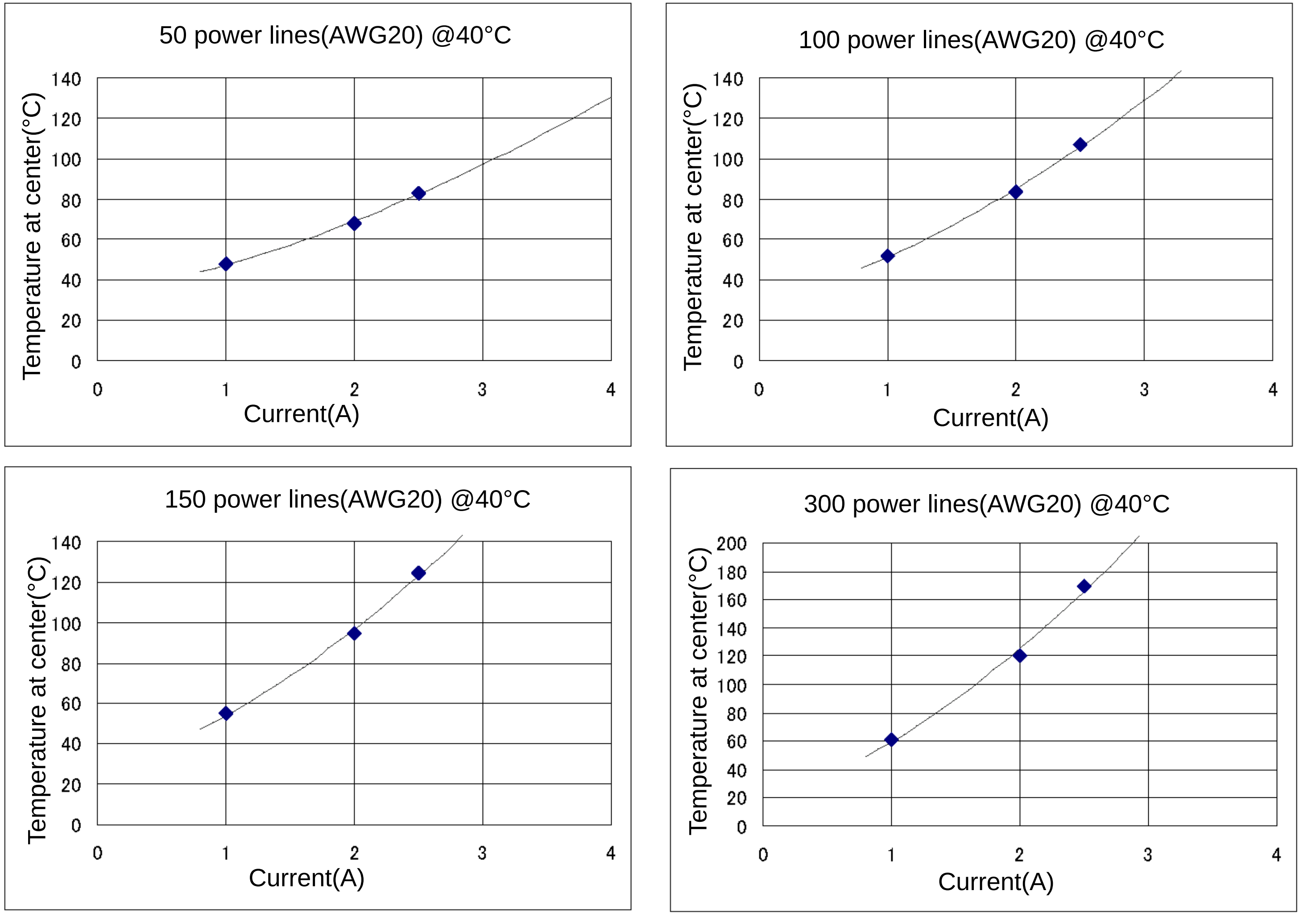


Figure II-1 Results of derating acquisition test conducted on bundled power lines only at an ambient temperature of 40°C

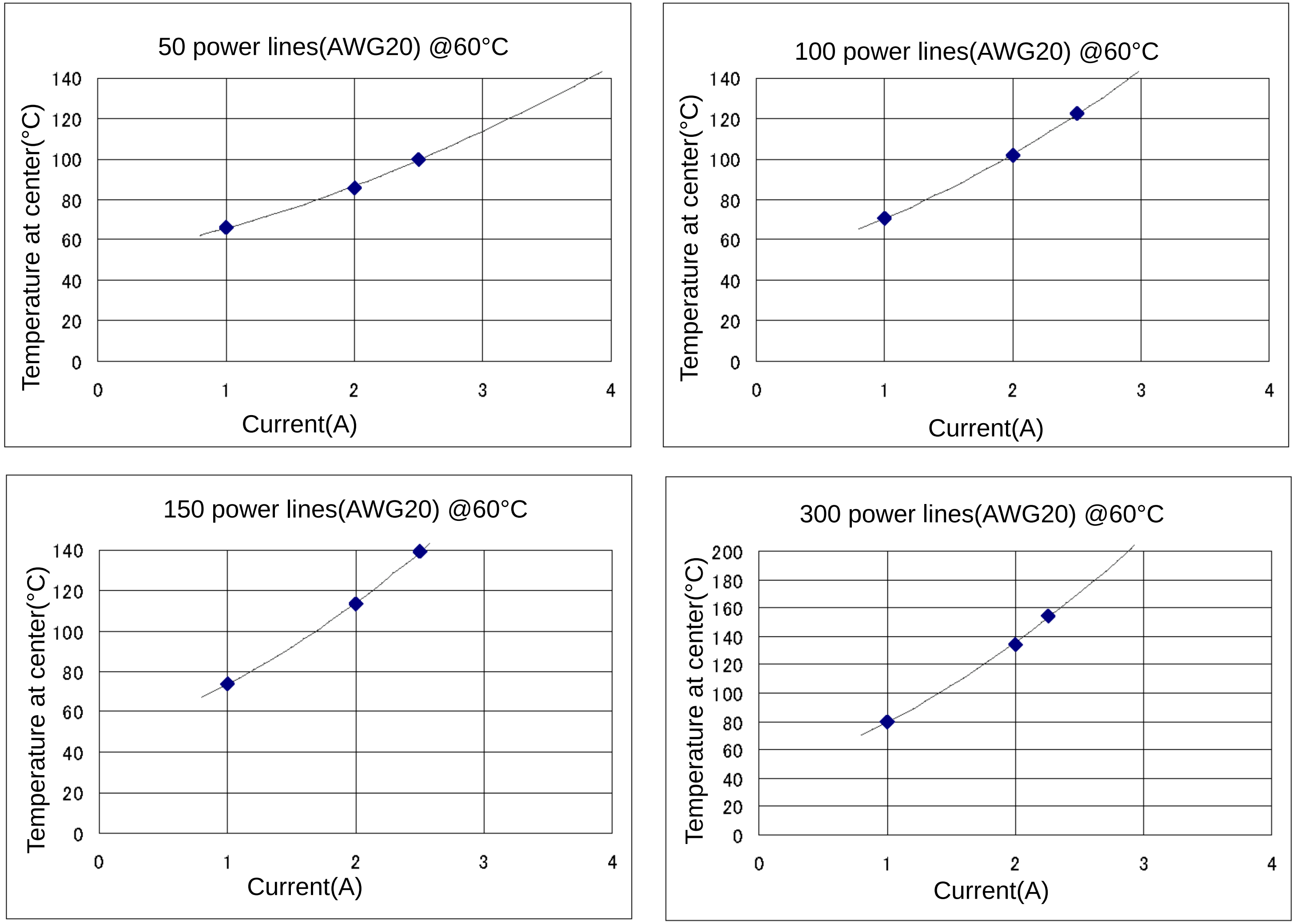


Figure II-2 Results of derating acquisition test conducted on bundled power lines only at an ambient temperature of 60°C

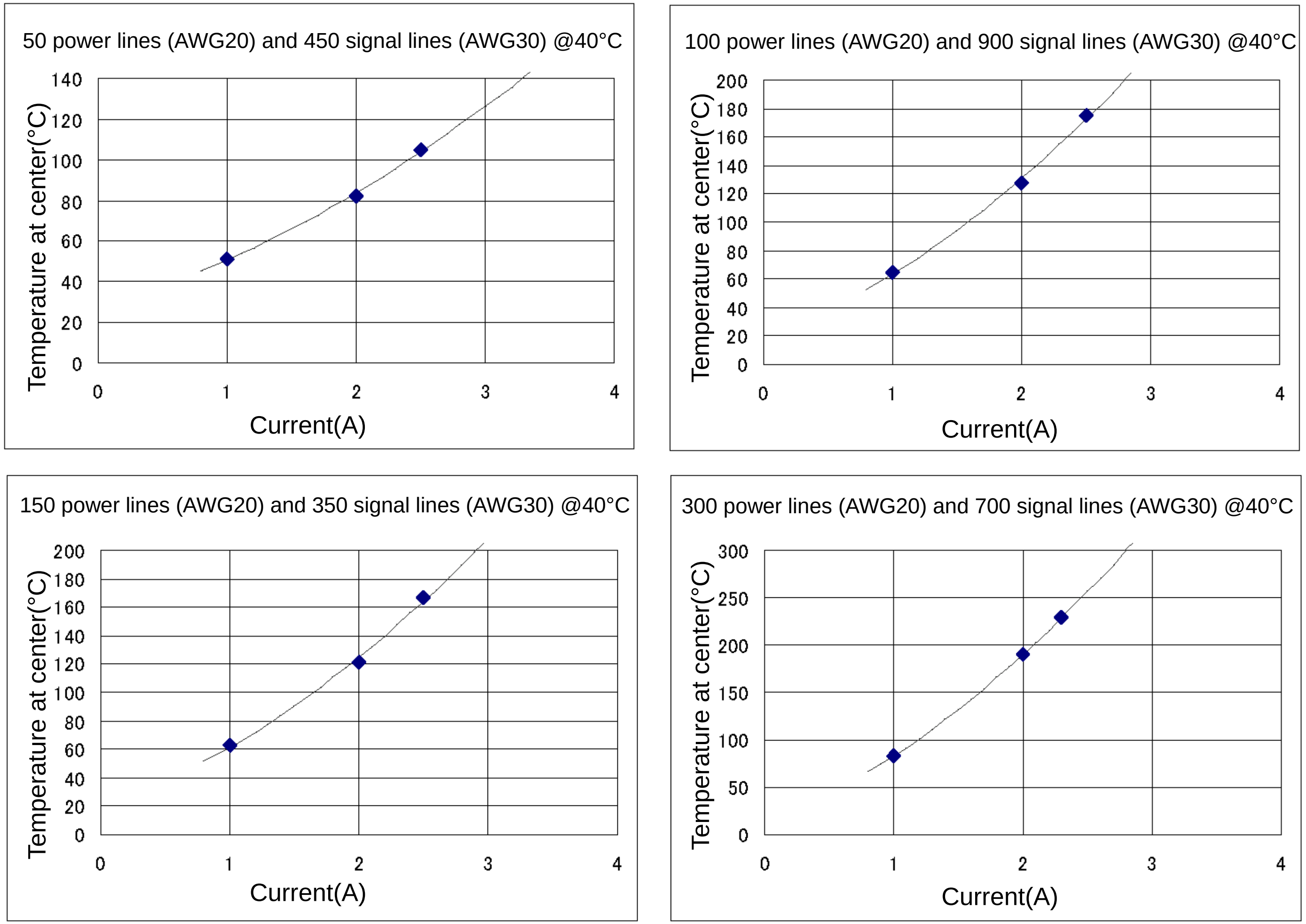


Figure II-3 Results of derating acquisition test conducted on mixed bundles of power and signal lines at an ambient temperature of 40°C

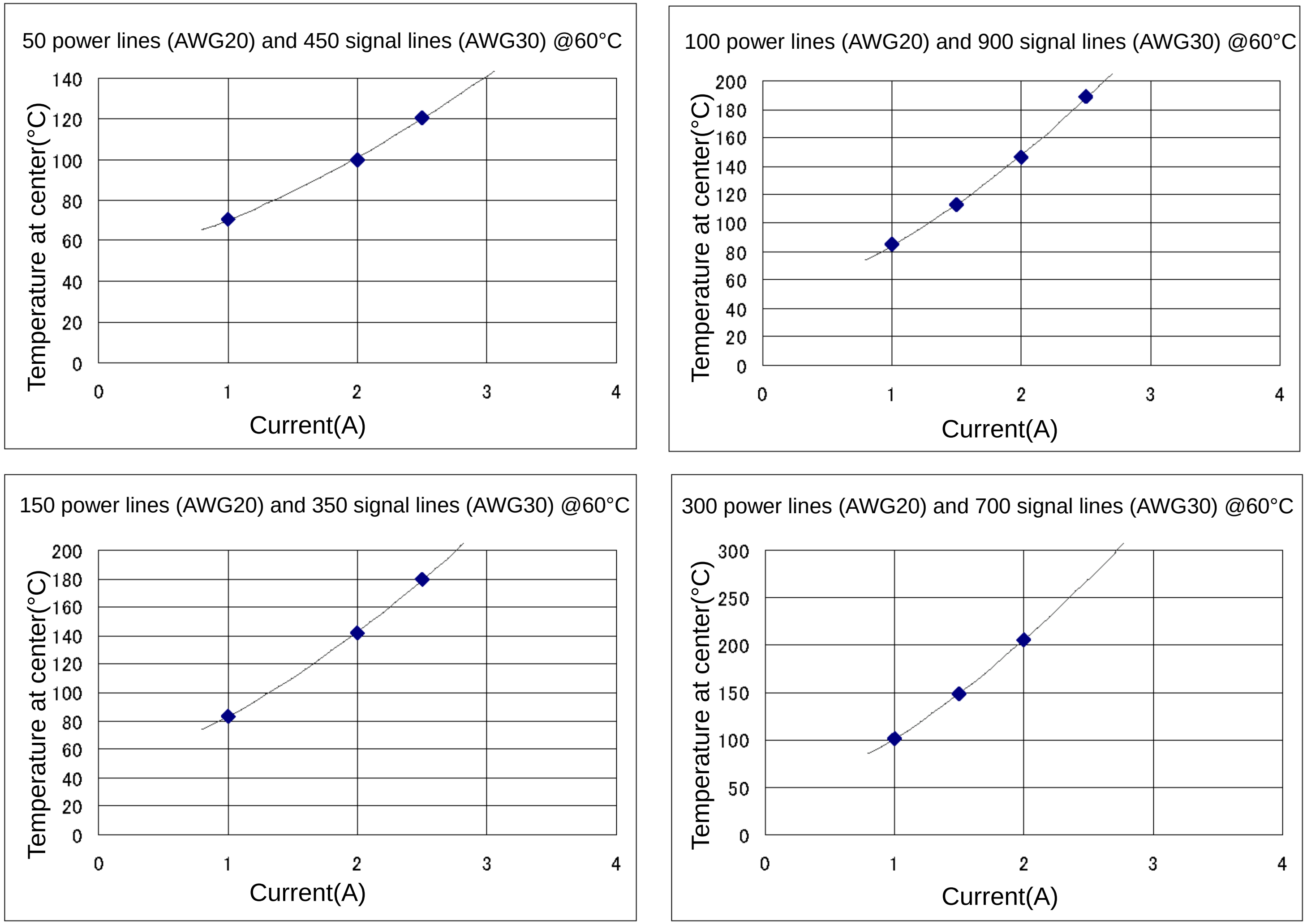
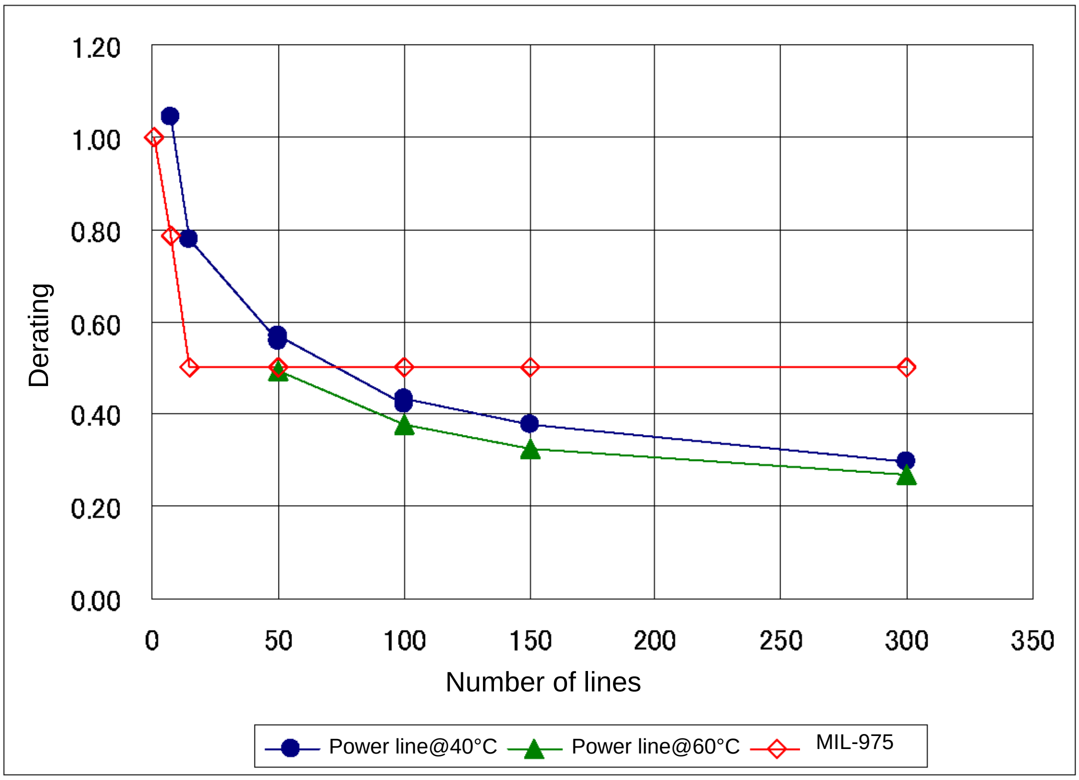


Figure II-4 Results of derating acquisition test on mixed bundles of power and signal lines at an ambient temperature of 60°C



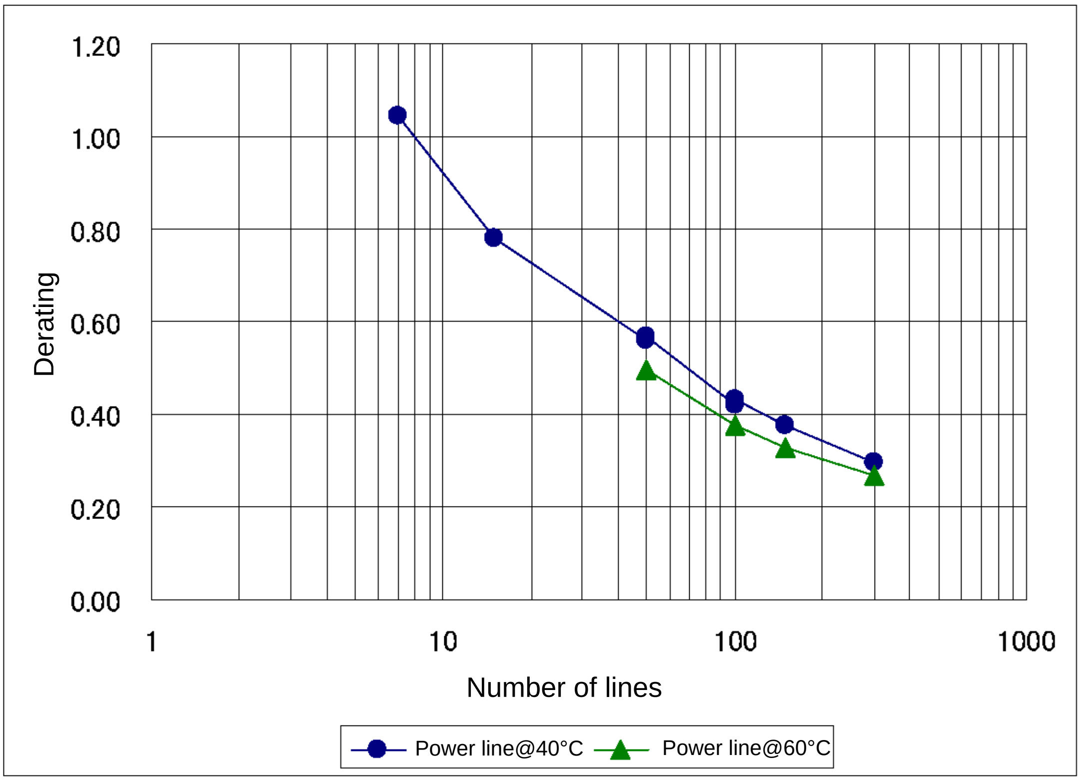


Figure II-5 Comparison by difference in ambient temperature

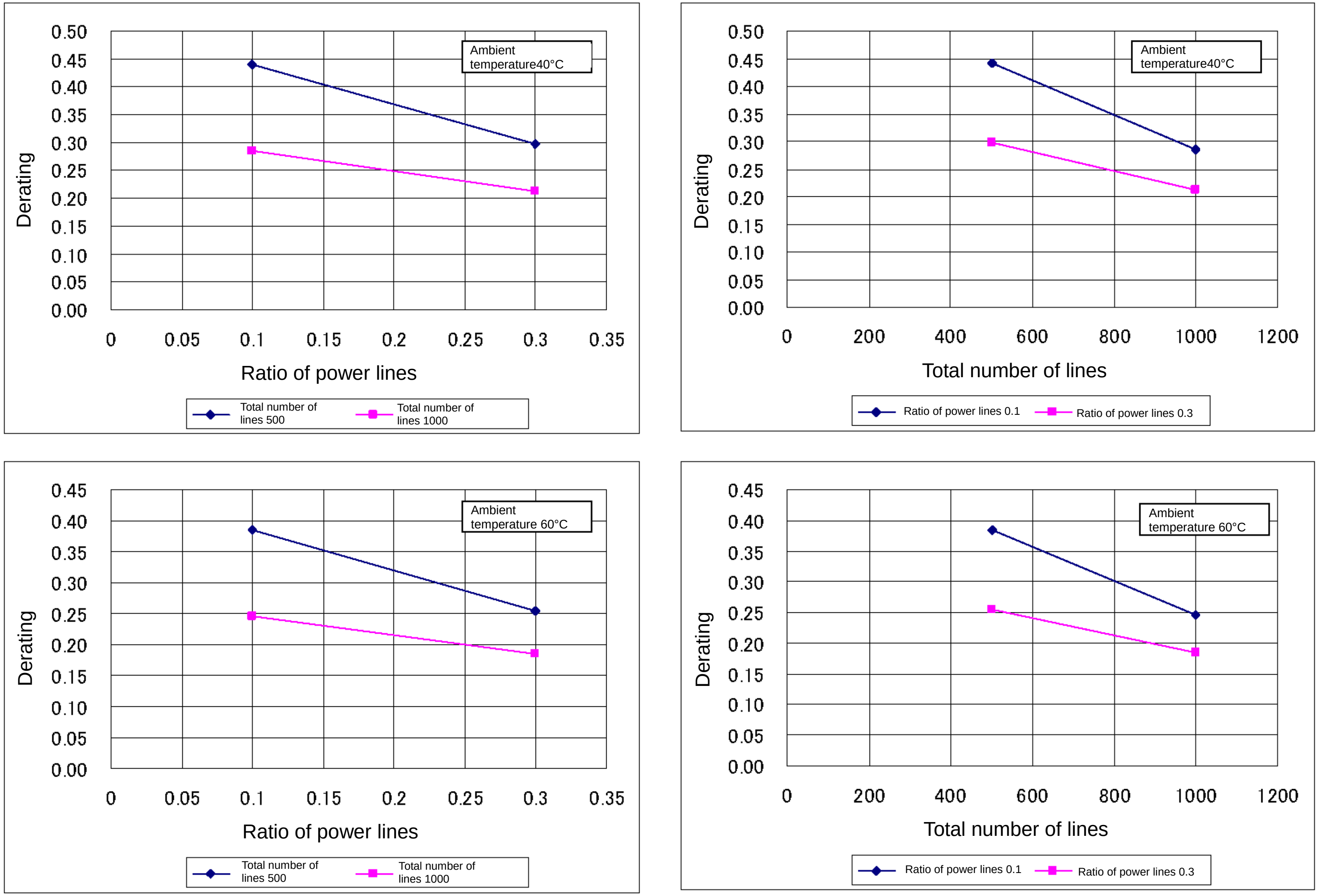


Figure II-6 Comparison by signal line ratio

References

1) Jun-ichiro Ishizawa, et. al.: ADEOS-II Harness Thermal Cycle Verification, Spacecraft Environment Symposium (2005)