THE CORRECTION FOR SPECTRAL MISMATCH EFFECTS ON THE CALIBRATION OF A SOLAR CELL WHEN USING A SOLAR SIMULATOR

JET PROPULSION LABORATORY
PASADENA, CA

JANUARY 81
The Correction for Spectral Mismatch Effects on the Calibration of a Solar Cell when Using a Solar Simulator

Clay H. Seaman

January 15, 1981

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 81-1)
1. Report No. JPL Pub. 81-1

4. Title and Subtitle
THE CORRECTION FOR SPECTRAL MISMATCH EFFECTS ON THE CALIBRATION OF A SOLAR CELL WHEN USING A SOLAR SIMULATOR

7. Author(s)

9. Performing Organization Name and Address
JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109

12. Sponsoring Agency Name and Address
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546

15. Supplementary Notes
Also sponsored by U.S. Department of Energy under Interagency Agreement DE-A101-76ET20356; identified as DOE/JPL-1012-50 and JPL Project Document 5101-169. (RTOP 776-52-61)

16. Abstract
A general expression has been derived to enable calculation of the calibration error resulting from simulator-solar AMX spectral mismatch and from reference cell-test cell spectral mismatch. The information required includes the relative spectral response of the reference cell, the relative spectral response of the cell under test, and the relative spectral irradiance of the simulator (over the spectral range defined by cell response). The spectral irradiance of the solar AMX is assumed to be known.

17. Key Words (Selected by Author(s))
Conversion Techniques
Energy Production
Energy Storage

18. Distribution Statement
Unclassified - Unlimited

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
9

22. Price
JPL 0184 11/8
The Correction for Spectral Mismatch Effects on the Calibration of a Solar Cell when Using a Solar Simulator

Clay H. Seaman

January 15, 1981

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

(JPL PUBLICATION 81-1)
ABSTRACT

A general expression has been derived to enable calculation of the calibration error resulting from simulator-solar AMX spectral mismatch and from reference cell-test cell spectral mismatch. The information required includes the relative spectral response of the reference cell, the relative spectral response of the cell under test, and the relative spectral irradiance of the simulator (over the spectral range defined by cell response). The spectral irradiance of the solar AMX is assumed to be known.
I. INTRODUCTION

Expressions for computing the error in short circuit current due to spectral mismatch (when using solar simulators) have been derived in the past (Reference 1), however none has had the generality required to be of universally predictive value. This paper describes the derivation of a general expression for the error and discusses some interesting points developed during that derivation. It also points out that relative spectral measurements will suffice and that absolute spectral measurements are not necessary.

II. PROCEDURE

Let a cell R be a reference cell calibrated (Reference 2) in AMX standard irradiance \( J_A \) so that its calibration factor \( K_{RA} \) is known and hence its short circuit current \( I_{RA} \) under that irradiance \( J_A \) is known. Under a source S of irradiance \( J_s \) (solar simulator) this cell R will produce a short circuit current \( I_{RS} \). Similarly, a cell C irradiated by \( J_A \) will produce \( I_{CA} \) and when irradiated by \( J_S \) will produce \( I_{CS} \).

The question now arises, can the standard cell R be used to measure (or adjust) the source S so that \( I_{CA} \) can be inferred from the measured \( I_{RS} \) and \( I_{CS} \)? That is, does

\[
\frac{I_{CS}}{I_{RS}} = \frac{I_{CA}}{I_{RA}}
\]

To be general, write Equation 1 as:

\[
\frac{I_{CS}}{I_{RS}} = M \frac{I_{CA}}{I_{RA}}
\]

and investigate the properties of \( M \). The previously discussed short circuit currents may be written as:

\[
\begin{align*}
I_{CS} &= \sum E_{Si} R_{Ci} \Delta_i \\
I_{RS} &= \sum E_{Si} R_{Ri} \Delta_i \\
I_{CA} &= \sum E_{Ai} R_{Ci} \Delta_i \\
I_{RA} &= \sum E_{Ai} R_{Ri} \Delta_i \\
\end{align*}
\]

where

\[
\begin{align*}
E_{Si} &= \text{Source S irradiance at spectral position } i \\
E_{Ai} &= \text{AMX irradiance at spectral position } i \\
R_{Ri} &= \text{Response of cell R at spectral position } i \\
\end{align*}
\]
$\text{R}_\text{Ci} = \text{Response of cell C at spectral position i}$

$\Delta_i = \text{ith spectral interval width}$

The sign $\Sigma$ will be taken to mean summation over all $i$.

Now Equation 2 can be written as:

$$\Sigma \text{E}_\text{Si} \text{R}_\text{Ci} \Delta_i / \Sigma \text{E}_\text{Si} \text{R}_\text{Ri} \Delta_i = \Sigma \text{E}_\text{Ai} \text{R}_\text{Ci} \Delta_i / \Sigma \text{E}_\text{Ai} \text{R}_\text{Ri} \Delta_i$$

Without loss of generality, let $\text{R}_\text{Ri} = \alpha_i \text{R}_\text{Ci}$ and $\text{E}_\text{Ai} = \beta_i \text{E}_\text{Si}$. Substituting these in Equation 3 gives

$$\Sigma \text{E}_\text{Si} \text{R}_\text{Ci} \Delta_i / \Sigma \text{E}_\text{Si} \alpha_i \text{R}_\text{Ci} \Delta_i = \Sigma \text{E}_\text{Si} \beta_i \text{E}_\text{Si} \text{R}_\text{Ci} \Delta_i / \Sigma \text{E}_\text{Si} \alpha_i \text{R}_\text{Ci} \Delta_i$$

(4)

It can be seen that if $\alpha_i \equiv \alpha$ a constant (implies $R$ and $C$ match spectrally), or if $\beta_i \equiv \beta$ a constant (implies $S$ and AMX match spectrally), then $\mathcal{M} \equiv 1$. In this case, i.e., spectral match, $\text{I}_\text{CS}/\text{I}_\text{RS} = \text{I}_\text{CA}/\text{I}_\text{RA}$. If now the source is adjusted so as to make $\text{I}_\text{RS} = \text{I}_\text{RA}$, then $\text{I}_\text{CS} = \text{I}_\text{CA}$, and the short circuit current of cell $C$ measured with source $S$ is just that which would be measured in AMX.

In the much more likely event that neither $\alpha_i$ nor $\beta_i$ is constant (that is, neither sources nor cells match spectrally), $\mathcal{M}$, which may be called the mismatch factor, will in general not be equal to unity. However, its value can be computed using Equation 3. Equation 3 may be considered the computation equation for $\mathcal{M}$, and Equation 2 may be considered the measurement equation for $\text{I}_\text{CA}$.

Notice from the form of Equation 3 that $\text{R}_\text{Ci}$, $\text{R}_\text{Ri}$ and $\text{E}_\text{Si}$ need only be relative quantities*. This becomes apparent if we suppose, for example, that the cell spectral response described by $\text{R}_\text{Ci}$ is only relative; then there is a constant $\eta$ such that the cell spectral response described by $\eta \text{R}_\text{Ci}$ is absolute. Substituting $\eta \text{R}_\text{Ci}$ for $\text{R}_\text{Ci}$ in the numerators of equation 3 we have:

$$\Sigma \text{E}_\text{Si} \eta \text{R}_\text{Ci} \Delta_i / \Sigma \text{E}_\text{Si} \text{R}_\text{Ri} \Delta_i = \Sigma \text{E}_\text{Ai} \eta \text{R}_\text{Ci} \Delta_i / \Sigma \text{E}_\text{Ai} \text{R}_\text{Ri} \Delta_i$$

Since $\eta$ is a constant, it may be taken outside the summation sign, and then dividing both sides by $\eta$, it is seen that equation 3 remains unchanged. Similar arguments hold for $\text{R}_\text{Ri}$ and $\text{E}_\text{Si}$. The importance of this must be emphasized, for now the onus of making absolute measurements of the spectral properties of sources and cells is removed.

---

*i.e., normalized to arbitrary but convenient references*
In addition to the relaxation of absolutism in the expression for computing $M$, notice that any errors in these measured spectral quantities tend to cancel, since each appears in both numerator and denominator. By contrast, if one were to compute any of the currents in isolation, not only are absolute values required, but all such errors appear fully weighted.

When the source $S$ is set so as to make $I_{RS} = I_{RA}$, and we measure $I_{CS}$, Equation 2 gives:

$$I_{CA} = I_{CS}/m$$

and since we have independently computed $M$ by Equation 3, we have determined the value of $I_{CA}$ as desired. Alternatively, if the simulator is set so as to make $M_{IRS} = I_{RA}$, we see that $I_{CS} = I_{CA}$ and the short circuit current of cell C measured under source $S$, as now set, is just that which would be measured in AMX.

When the mismatch is ignored, or, in other words, when $M$ is assumed to be unity (as is conventionally done), the fractional error $\varepsilon$ due to equating $I_{CS}$ with $I_{CA}$ will be $\varepsilon = (I_{CS} - I_{CA})/I_{CA}$. Using Equation 5,

$$\varepsilon = (M I_{CA} - I_{CA})/I_{CA} = m - 1$$

III. CONCLUSION

The derived expression for the mismatch factor $M$ (Equation 3) allows any radiant source of known relative spectral irradiance (known over the spectral range of cell response) to be used to calibrate any cell of known relative spectral response. A standard AMX reference cell of known relative spectral response is required to set the irradiance of the source. Specifically:

1. If the simulator is set so as to make $I_{RS} = I_{RA}$, the measured $I_{CS}$ will equal $M I_{CA}$.
2. If the simulator is set so as to make $M_{IRS} = I_{RA}$, the measured $I_{CS}$ will equal $I_{CA}$.
3. If mismatch is ignored, the fractional error in $I_{CA}$ is $\varepsilon = M - 1$. 
REFERENCES


NTIS does not permit return of items for credit or refund. A replacement will be provided if an error is made in filling your order, if the item was received in damaged condition, or if the item is defective.

This report was printed specifically for your order from our collection of more than 2 million technical reports.

For economy and efficiency, NTIS does not maintain stock of its vast collection of technical reports. Rather, most documents are printed for each order. Your copy is the best possible reproduction available from our master archive. If you have any questions concerning this document or any order you placed with NTIS, please call our Customer Services Department at (703)487-4660.

Always think of NTIS when you want:
- Access to the technical, scientific, and engineering results generated by the ongoing multibillion dollar R&D program of the U.S. Government.
- R&D results from Japan, West Germany, Great Britain, and some 20 other countries, most of it reported in English.

NTIS also operates two centers that can provide you with valuable information:
- The Federal Computer Products Center - offers software and datafiles produced by Federal agencies.
- The Center for the Utilization of Federal Technology - gives you access to the best of Federal technologies and laboratory resources.

For more information about NTIS, send for our FREE NTIS Products and Services Catalog which describes how you can access this U.S. and foreign Government technology. Call (703)487-4650 or send this sheet to NTIS, U.S. Department of Commerce, Springfield, VA 22161. Ask for catalog, PR-827.

Name
Address
Telephone

- Your Source to U.S. and Foreign Government Research and Technology.