

**U.S. Department of Commerce
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N81-20546

**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

5101-169
Low-Cost
Solar Array Project

DOE/JPL-1012-50
Distribution Category UC-63b

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

Clay H. Seaman

(NASA-CR-164074) THE CORRECTION FOR
SPECTRAL MISMATCH EFFECTS ON THE CALIBRATION
OF A SOLAR CELL WHEN USING A SOLAR SIMULATOR
(Jet Propulsion Lab.) 10 p HC A02/MF A01

N81-20546

CSSL 10A G3/44

Unclas
41907



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	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle THE CORRECTION FOR SPECTRAL MISMATCH EFFECTS ON THE CALIBRATION OF A SOLAR CELL WHEN USING A SOLAR SIMULATOR		5. Report Date January 15, 1981	
		6. Performing Organization Code	
7. Author(s)		8. Performing Organization Report No.	
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91109		10. Work Unit No.	
		11. Contract or Grant No. NAS 7-100	
		13. Type of Report and Period Covered JPL Publication	
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		14. Sponsoring Agency Code	
15. Supplementary Notes Also sponsored by U.S. Department of Energy under Interagency Agreement DE-AI01-76ET20356; identified as DOE/JPL-1012-50 and JPL Project Document 5101-169. (RTOP 776-52-61)			
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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

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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.

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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

$$I_{CS}/I_{RS} \stackrel{?}{=} I_{CA}/I_{RA} \quad (1)$$

To be general, write Equation 1 as:

$$I_{CS}/I_{RS} = m I_{CA}/I_{RA} \quad (2)$$

and investigate the properties of m . The previously discussed short circuit currents may be written as:

$$I_{CS} = \sum E_{Si} R_{Ci} \Delta_i$$

$$I_{RS} = \sum E_{Si} R_{Ri} \Delta_i$$

$$I_{CA} = \sum E_{Ai} R_{Ci} \Delta_i$$

$$I_{RA} = \sum E_{Ai} R_{Ri} \Delta_i$$

where

E_{Si} = Source S irradiance at spectral position i

E_{Ai} = AMX irradiance at spectral position i

R_{Ri} = Response of cell R at spectral position i

R_{Ci} = Response of cell C at spectral position i

Δ_i = ith spectral interval width

The sign Σ will be taken to mean summation over all i.

Now Equation 2 can be written as:

$$\Sigma E_{Si} R_{Ci} \Delta_i / \Sigma E_{Si} R_{Ri} \Delta_i = \mathcal{M} \Sigma E_{Ai} R_{Ci} \Delta_i / \Sigma E_{Ai} R_{Ri} \Delta_i \quad (3)$$

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

$$\Sigma E_{Si} R_{Ci} \Delta_i / \Sigma E_{Si} \alpha_i R_{Ci} \Delta_i = \mathcal{M} \Sigma \beta_i E_{Si} R_{Ci} \Delta_i / \Sigma \beta_i E_{Si} \alpha_i R_{Ci} \Delta_i \quad (4)$$

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, $I_{CS}/I_{RS} = I_{CA}/I_{RA}$. If now the source is adjusted so as to make $I_{RS} = I_{RA}$, then $I_{CS} = I_{CA}$, 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 α_i nor β_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 I_{CA} .

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

$$\Sigma E_{Si} \eta R_{Ci} \Delta_i / \Sigma E_{Si} R_{Ri} \Delta_i = \mathcal{M} \Sigma E_{Ai} \eta R_{Ci} \Delta_i / \Sigma E_{Ai} R_{Ri} \Delta_i$$

Since η is a constant, it may be taken outside the summation sign, and then dividing both sides by η , it is seen that equation 3 remains unchanged. Similar arguments hold for R_{Ri} and E_{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:

$$I_{CA} = I_{CS}/m \quad (5)$$

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 $mI_{RS} = I_{RA}$, 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 ϵ due to equating I_{CS} with I_{CA} will be $\epsilon = (I_{CS} - I_{CA})/I_{CA}$. Using Equation 5,

$$\begin{aligned} \epsilon &= (m I_{CA} - I_{CA})/I_{CA} \\ &= m-1 \end{aligned}$$

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 mI_{CA} .
- (2) If the simulator is set so as to make $mI_{RS} = I_{RA}$, the measured I_{CS} will equal I_{CA} .
- (3) If mismatch is ignored, the fractional error in I_{CA} is $\epsilon = m-1$.

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