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

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Clay H. Seaman

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U.S. Department of Energy
Through an agreement with
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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.
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:

$$\frac{I_{CS}}{I_{RS}} = \mathcal{M} \frac{I_{CA}}{I_{RA}}$$

and investigate the properties of $\mathcal{M}$. 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
\[ R_{Ci} = \text{Response of cell C at spectral position } i \]

\[ \Delta_i = \text{ith spectral interval width} \]

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

Now Equation 2 can be written as:

\[
\sum E_i R_{Ci} \Delta_i / \sum E_i R_{Ri} \Delta_i = \sum E_i R_{Ci} \Delta_i / \sum E_i R_{Ri} \Delta_i
\]

Without loss of generality, let \( R_{Ri} = \alpha_i R_{Ci} \) and \( E_{Ai} = \beta_i E_{Si} \).

Substituting these in Equation 3 gives

\[
\sum E_i R_{Ci} \Delta_i / \sum E_i \alpha_i R_{Ci} \Delta_i = \sum E_i \beta_i E_{Si} R_{Ci} \Delta_i / \sum E_i \alpha_i R_{Ci} \Delta_i
\]

It can be seen that if \( \alpha_i = \alpha \) a constant (implies \( R \) and \( C \) match spectrally), or if \( \beta_i = \beta \) a constant (implies \( S \) and \( AMX \) match spectrally), then \( \mathcal{M} = 1 \).

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 \( \alpha_i \) 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 \( I_{CA} \).

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 \( n \) such that the cell spectral response described by \( nR_{Ci} \) is absolute. Substituting \( nR_{Ci} \) for \( R_{Ci} \) in the numerators of equation 3 we have:

\[
\sum E_i nR_{Ci} \Delta_i / \sum E_i R_{Ri} \Delta_i = \sum E_i \beta_i E_{Si} nR_{Ci} \Delta_i / \sum E_i R_{Ri} \Delta_i
\]

Since \( n \) is a constant, it may be taken outside the summation sign, and then dividing both sides by \( n \), 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.

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* 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:

\[
I_{CA} = I_{CS}/m
\]  

(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 \( m I_{RS} = I_{RA} \), 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 \( \varepsilon \) 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 \( m I_{RS} = I_{RA} \), the measured \( I_{CS} \) will equal \( I_{CA} \).

(3) If mismatch is ignored, the fractional error in \( I_{CA} \) is \( \varepsilon = m - 1 \).
REFERENCES

