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Analog signal functional converters for solar array simulators

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Abstract. In the article authors describe different types of functional converters for solar array simulators. Functional converter used to get nonlinear current to voltage characteristic on solar array simulator output. Described and studied two types of digital functional converters and compared with analog functional converter.

1. Introduction

At the present time solar array simulators (SAS) are widely used in terrestrial tests of spacecraft power system with solar arrays as primary power sources. Solar array simulators are special power sources, which are reproducing main output characteristics of solar array (SA) as I-V curve and admittance.

Solar array simulators developed and produced by the authors use functional feedback (FF) to obtain required characteristics. Solar array simulators usually built as current stabilizer with load voltage functional feedback presented as functional converter (FC) to reproduce required

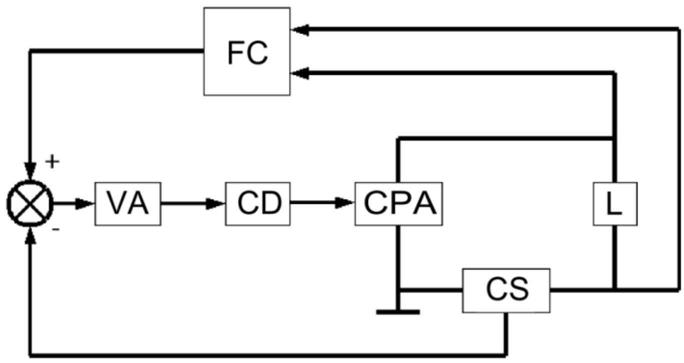

Figure 1. Structure of SAS with functional feedback by load voltage. FC – functional converter, L – load, CS – current sensor, VA – voltage amplifier, CD – correction device, CPA – continuous power amplifier

I-V curve and amplifiers to set I-V curve working range. Structure of SAS shown on Figure 1.

In [1,2] it is shown that FF properties has significant influence on accuracy and dynamical characteristics of SAS, generally: I-V curve reproduction accuracy, SAS bandwidth and output admittance. At the same time FF properties are mostly depends on functional converter realization and characteristics. Therefore, a point of interest is a development of functional converter providing required static and dynamical characteristics of SAS.

2. Functional converters classification

Functional converters classification contain three groups by realization method:

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- Reference FC in which nonlinear characteristic obtained by real solar array (or cell) placed in given irradiation, light intensity, temperature, etc. This method was widely used in USA solar array simulators [3].
- Diode type FC. Based on diode I-V curve, which are exponential and roughly can represent I-V curve of solar array [4].
- Circuit FC. Nonlinear I-V curve obtained by scheme on discrete elements. Circuit FC can be of analog type (in which nonlinear circuit based on continuous elements) and digital type in which input signal converted to digital form before processing.

Reference FC considered difficult to realize, because of large number of special hardware such as special lamps, heat chamber, etc. to reproduce orbital environment for reference solar cell or solar array. Due to given difficulties this type of FC has limited usage.

FC of diode type easily realized in comparison with reference FC and circuit FC, but it provides less customizable I-V curve and often does not reproduce real solar array I-V curve. Furthermore, diode also has dependence of I-V curve from environment temperature, which should be considered during solar array simulator development.

Analog FC of circuit type based on transistor scheme [2] can reproduce I-V curve by number of segments, depending on number of transistors. Use of this FC together with scaling amplifiers on FC input and output provides broad range of solar array working modes such as shadowing, temperature change, emergency cases and so on. Main disadvantages of this scheme are fixed I-V curve shape, setup complexity and relatively low reproduction accuracy.

Latest developments in given field are digital functional converters (DFC) which are based on analog-to-digital conversion (ADC) followed by digital signal processing by microcontrollers, DSP, FPGA, logic, etc. This kind of FC provides much more flexible configuration of I-V curve, ability to change I-V curve during test, simplicity of setup and development, higher noise immunity.system should provide continuous long-time testing of accumulators including current and voltage protections and emergency stop in case of energy breakdown.

3. Digital functional converters

Digital FC has three main realizations:

- Calculating FC, which uses microcontroller to calculate output for every input value [5].
- Lookup table FC, based on memory with predefined output values for every input signal value.
- Logic FC based on FPGA containing complex scheme to realize some logic function to convert input values into output.

Regardless of digital signal processor (DSP) digital FC always should make digital-to-analog signal conversion on output.

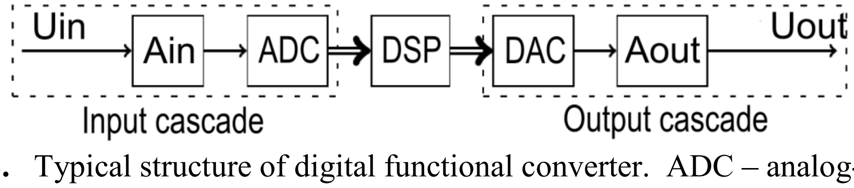

Figure 2. Typical structure of digital functional converter. ADC – analog-to-digital converter, DSP – digital signal processor, DAC – digital-to-analog conveter, Ain, Aout – input and output scaling amplifiers.

Typical structure of digital FC shown on Figure 2.

Digital FC can also be used with scaling amplifiers on input (Ain) and output (Aout) as in case of analog FC to improve accuracy in cases of limited I-V curve region used. For example if maximum current is set to 160 Amperes, but reproduced I-V curve uses only region from 0 to 80 Amperes, effective usage of current range is 0.5. With ADC or DAC resolution of 12-bits it means that in fact only 11 bits will be used. Scaling amplifier can change effective input and output range of digital FC to match used region and FC will operate in full resolution.

One of main drawbacks of digital FC is worse dynamical characteristics which lead to lower reproduction accuracy of SA admittance. This drawback comes from limited analog-to-digital and digital-to-analog conversion speed. In scheme functional converted can be represented as two elements: nonlinear function and signal delay caused by conversion. As functional converter placed in feedback loop of SAS, it leads to effect of parasitic capacitance on SAS output. From SAS admittance equation [2]:

$$Y_{SAS}(s,U) = \frac{Y_{DSA}(U) + Y_{Csas}(s,U)}{1 + R_{PSA}\left(1/R_{DSA}(U) + C_{SAS}(s,U)\right)}$$

We can see that increase of CSAS has significant influence on SAS admittance.

4. Results

The authors studied characteristics and compared three types of functional converters: analog FC with scaling amplifiers, digital FC on lookup table and digital calculating FC. Study was done on two experiments: dynamical characteristics of entire FC and SAS dynamical characteristics with each type of FC.

Experiment on FC dynamical characteristics give us bode diagram for FC, which contain magnitude and phase. On Figure 3 shown phase plot for both digital FC types, from which we can see that lookup table FC has much lower phase shift and therefore has less effect on output SAS capacitance.

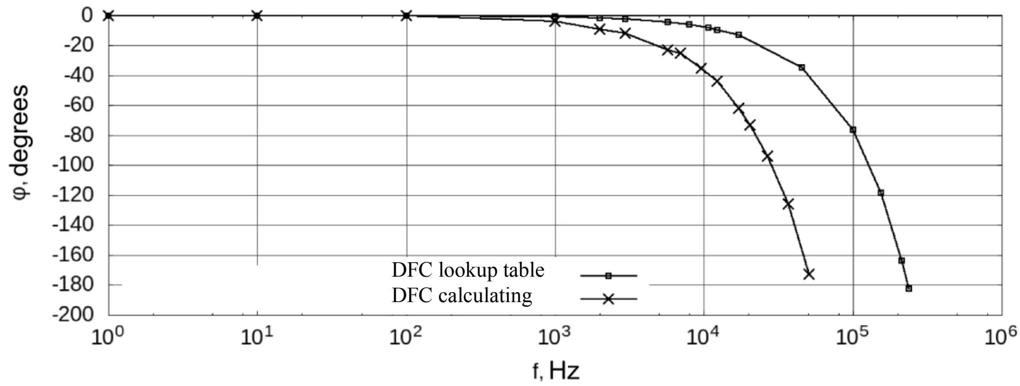

Figure 3. Phase plot of lookup table digital FC and calculating digital FC.

To study effect on SAS output capacitance measured admittance of SAS with analog FC (used as reference) and digital FC with lookup table. Results shown on Figure 4.

Comparison of SAS admittance for digital and analog FC cases shows that characteristics are just similar and on practice analog FC can be replaced by digital FC in SAS, this will allow to get much more functions of SAS like exact change of I-V curve shape.

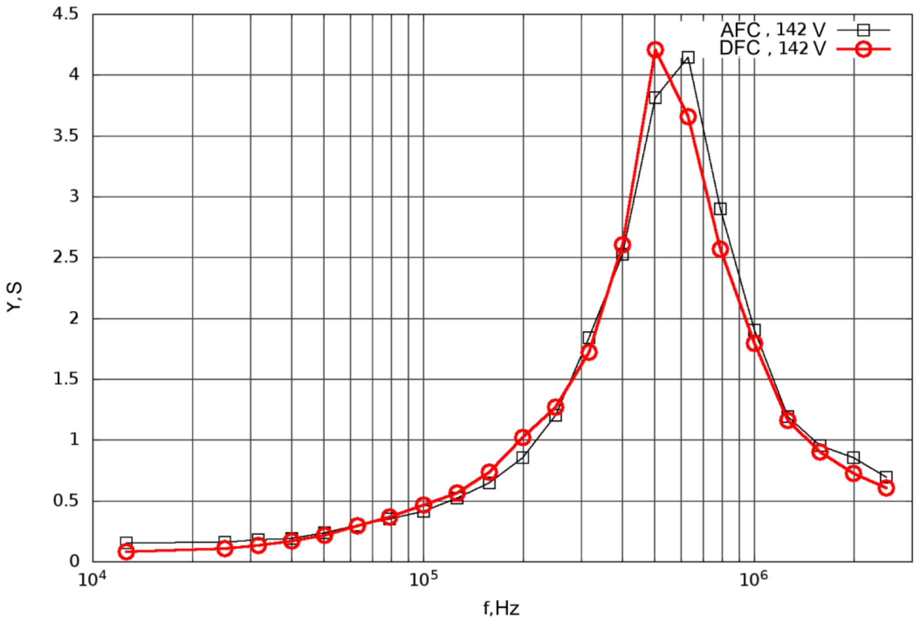

Figure 4. Phase plot of lookup table digital FC and calculating digital FC.

Acknowledgments

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