Agilent AN 1293
Sequential Shunt Regulation

Application Note

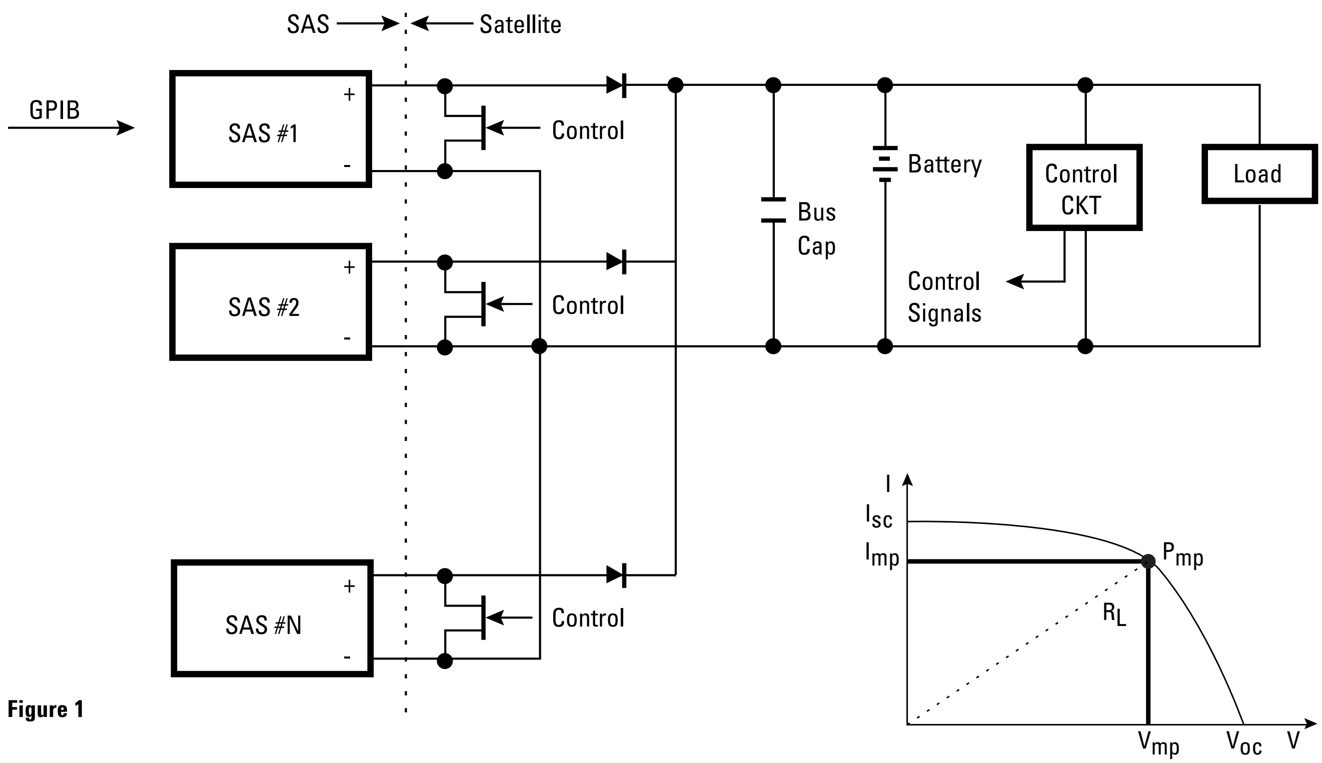

Figure 1

Figure 2

I_{sc}= short circuit current
I_{mp}= current at the maximum power
V_{mp}= voltage at the maximum power
V_{oc}= open circuit voltage
P_{mp}= maximum power point
R_L= load line

Regulating Satellite Bus Voltage

The sequential shunt regulator is widely used for regulating the satellite bus voltage. A simplified sequential shunt concept is shown in Figure 1.

The Agilent Technologies E4350B/ E4351B Solar Array Simulators (SAS) are ideal for this type of application. Operating in this mode, the current either flows into the load or into the shunt control FETs. The shunt control FET will be referred to as the shunt or the switch for the remainder of the paper. Figure 2 shows a typical solar array I-V curve. As an example, let's assume operation at the maximum power point. When the shunt is open, the current to the load will be I_{mp} (current at the maximum power point). When the shunt is closed, the current in the shunt is I_{sc} (short circuit current). Figure 3 shows the output waveforms across one SAS. The output current of the SAS is basically constant because the difference between I_{mp} and I_{sc} is usually small but the voltage changes from a short (switch on) to V_{mp} (switch off).

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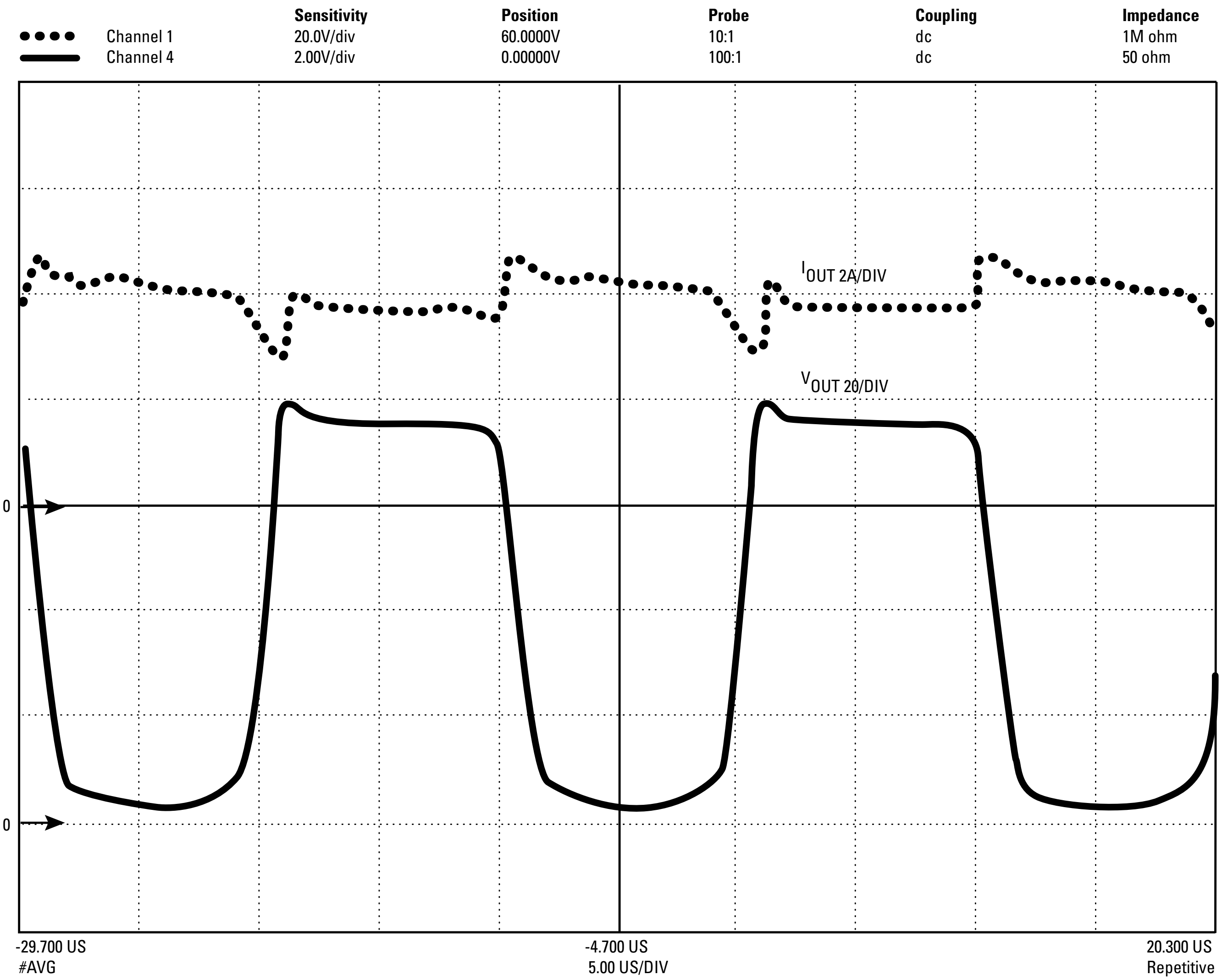

Figure 3

If bus voltage = V_{mp}, then Output power delivered to the bus = (1-D) (N) (P_{mp}) where: D = On duty cycle of the shunt FET, N = Number of SAS supplies, P_{mp} = Maximum power point. To satisfy the power demands of the power system of the satellite, the output voltage of the SAS has to rise within 2 to 10 usec when the shunt is opened and the operating point changes from the short circuit point to the operating load point on the curve. The E4350B/E4351B low output capacitance (<50 nF) allows this fast rise time and also limits the turn on switching losses in the shunt switch. The E4350B/E4351B can handle switching frequencies up to 50 KHz. Figure 3 shows the output voltage and current of the E4351B when the shunt switches at 50 KHz with shunt FET rise and fall times of 2 usec. For this test, the E4351B is in Simulator mode (refer to data sheet) and the I-V curve defined by these four parameters: I_{sc} = 4.00A, I_{mp} = 3.75A, V_{mp} = 120V and V_{oc} =130V.

The wire inductance in the test circuit is very small. As the inductance increases, the voltage overshoot on the output voltage will increase, but will be limited by fast acting internal clamp circuits. The overshoot and undershoot in the current (Figure 3) are due to the internal output snubber, as part of the output capacitance, charging and discharging. Note that in Figure 1, the bus capacitor across the battery is required to smooth the bus current and lower the ripple.

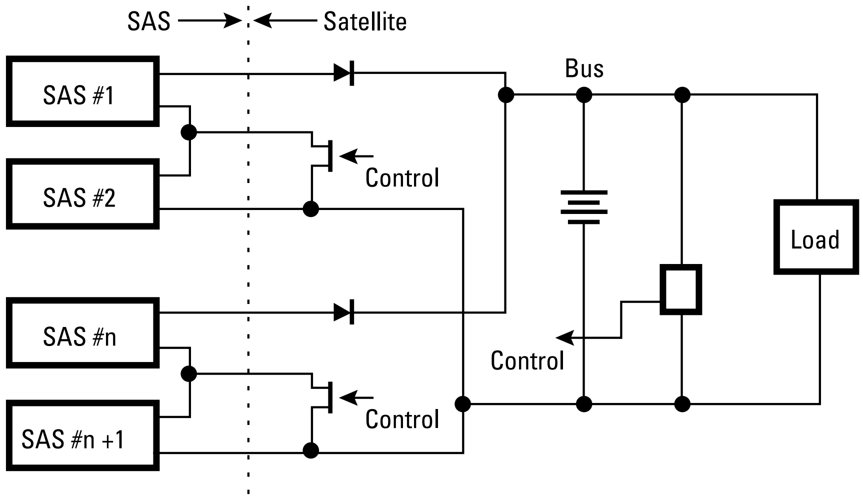

Figure 4

Figure 1 shows diodes in series with each output of the SAS (after the shunt). These diodes isolate the supplies so that when one shunt is on, the output of the other SAS's is not pulled low. The diodes should have very fast recovery time, otherwise the power dissipation in the diode and the shunt FET will be high. Higher levels of noise will also occur if slow diodes are used, or if the FET rise and fall times are too fast. The latter can be controlled by adjusting the FET gate resistor. Snubber (RC) across the diodes may help reduce the switching noise and voltage overshoots. A heatsink may be needed to keep the diode cool and within the temperature ratings.

Voltage and current ratings of the shunt switch are determinedby the V_{oc} and I_{sc} parameters.

The heatsink design for the switch will depend on the switching frequency and the duty cycle and the output current. Higher switching frequency and higher duty cycle (ON time) will increase the power dissipation in the shunt FET.

A different sequential shunt that some customers use is shown in Figure 4. In this configuration, the bus voltage cannot be lower than the output voltage of the upper SAS. Since only one half of the string is shunted, the bus voltage will always have a minimum voltage that is at least half of the string. The major advantage of this technique is that it reduces the power dissipation in the FET by reducing the switching losses because the voltage across the FET is half. It may also make the selection of the FET easier since a lower voltage part can be used. Sometimes a linear device is used instead of a switch in order to have better control on the voltage, but this results in higher power dissipation in the linear device.

In the sequential shunt configuration, the number of strings is limited by the total power required. When using the E4350B/E4351B, strings may be added or subtracted as necessary for the particular application. Each string is programmable over the IEEE-488.2 bus using SCPI (standard commands for programmable instruments) commands.

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