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# Operation of High Power Converters in Parallel

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# OPERATION OF HIGH POWER CONVERTERS IN PARALLEL

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## ABSTRACT

High power converters that are used in space power subsystems are limited in power handling capability due to component and thermal limitations. For applications, such as Space Station Freedom, where multi-kilowatts of power must be delivered to user loads, parallel operation of converters becomes an attractive option when considering overall power subsystem topologies. TRW, under NASA contract NAS3-25093, has developed three different unequal power sharing approaches for parallel operation of converters. These approaches, known as droop, master-slave, and proportional adjustment, are discussed in this paper and test results are presented.

## INTRODUCTION

TRW, under NASA contract NAS3-25093, has developed three different power sharing approaches for parallel operation of the Space Station Freedom 6.25 kW DC-DC converter units (DDCU). These approaches, known as droop, master-slave, and proportional adjustment, have been incorporated in the TRW breadboard DDCUs used in the space station power management and distribution (PMAD) dc test bed at Lewis Research Center, where system operation has been verified.

### 6.25 kW DC-DC Converter Unit Description

The 6.25 kW DDCU provides isolation between the space station main bus and the 120 vdc secondary bus. The DDCU block diagram, as shown in Figure 1, consists of an input filter, a 20 kHz series resonant dc-ac inverter, output rectifiers, and an output filter. The control electronics provide output regulation and output current limit functions. A dc-dc converter operating from the main input voltage provides control power for the DDCU. A Mil-Std-1553 data bus controller interfaces command and telemetry functions between the DDCU and the space station

controllers. The series resonant inverter concept of the DDCU is based on the parallel resonant inverter that was used in the main inverter unit (MIU) for the space station 20 kHz power subsystem. The series resonant inverter power stage schematic is shown in Figure 2. It includes two insulated gate bipolar transistor (IGBT) power switches, Q1 and Q2, that operate at 50% duty cycle and two IGBT power switches, Q3 and Q4, that operate in a pulse width modulated fashion to control output voltage or output current. A unique feature of this concept is that no energy is ever returned to the source.

The converter operates from a 125-170 vdc bus and provides a regulated output voltage which is programmable from 120 to 138 vdc. Efficiency curves from two 6.25 kW units operating in parallel are shown in Figure 3.

### Current Mode Master/Slave Control

In the current program method of control, forced current sharing of multiple power stages is not necessary, since a common error signal controls the peak currents in each power stage, resulting in automatic current sharing. A block diagram implementation of the current mode master/slave control is shown in Figure 4. An error amplifier compares the output voltage against a reference and generates an error voltage  $E_o$ , that is used as a reference for the comparators to control the switch currents in each power stage. A ramp is added for stability. The output of the comparator is the PWM signal that controls the turn-on and turn-off of the power transistors in each power stage. In this control scheme, the two power channels share current equally. Switch currents for each channel are shown in Figure 5. Output current sharing data is presented in Figure 6.

### Current Mode Proportional Adjustment Control

The current mode proportional adjustment control method is similar to the master/slave control with one exception. A multiplier is added in series with the output error signal to modify the reference for the PWM comparators (See Figure 7). By commanding different ratio references into the multipliers, unequal power sharing can be obtained from the converters. With both of the ratio commands set to 100 percent, the current sharing shown in Figure 6 is obtained. By offsetting the ratios, one at 100 percent and the other at 90 percent, the current sharing shown in Figure 8 is obtained. By changing the ratios, other current sharing values can be obtained.

### Droop Mode Control

The third power sharing approach is the droop mode control. This approach, unlike the other two, does not require any control signals to be shared between the two

parallel converters. Power sharing, whether equal or unequal is accomplished by drooping the output voltage regulation point as a function of its load current. a block diagram implementation is presented in Figure 9. An error signal which is proportional to output current is introduced into the output voltage divided as shown in Figure 9. As output current increases, the voltage regulation point droops, resulting in a negative feedback effect when two converters are connected in parallel. By adjusting the current to voltage ratio of the divider current feedback network for each converter, equal or unequal output current sharing can be achieved. Figure 10 shows data for equal current sharing of the converters operating in the droop mode control. Figure 11 shows data for unequal current sharing for various current to voltage ratio.

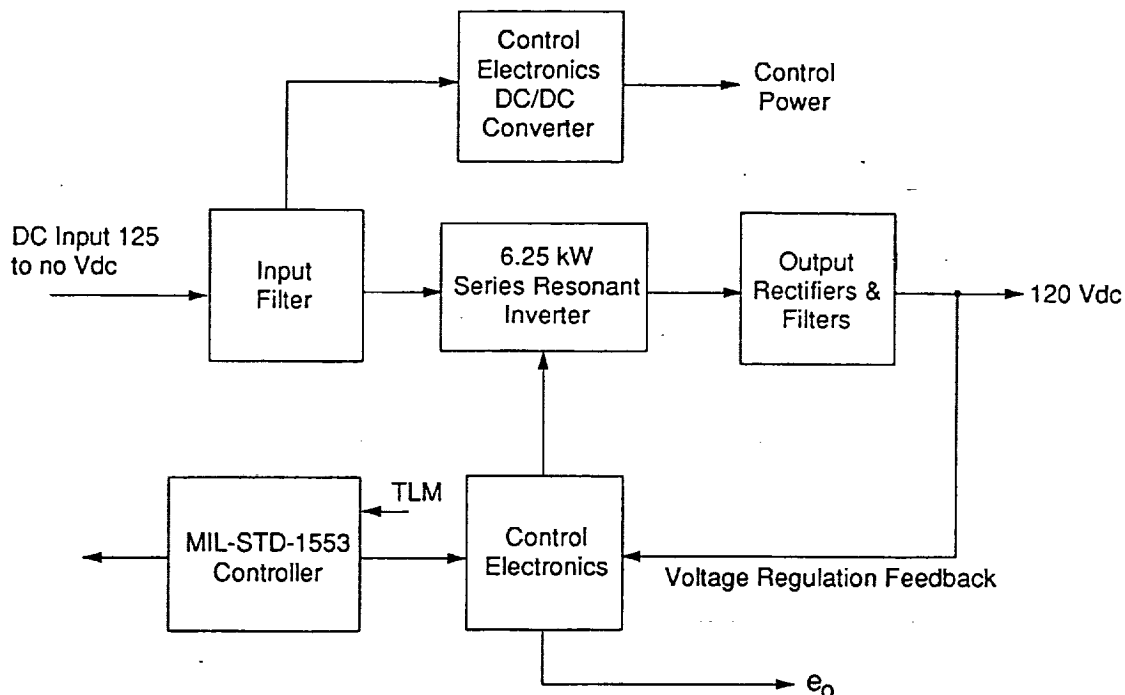
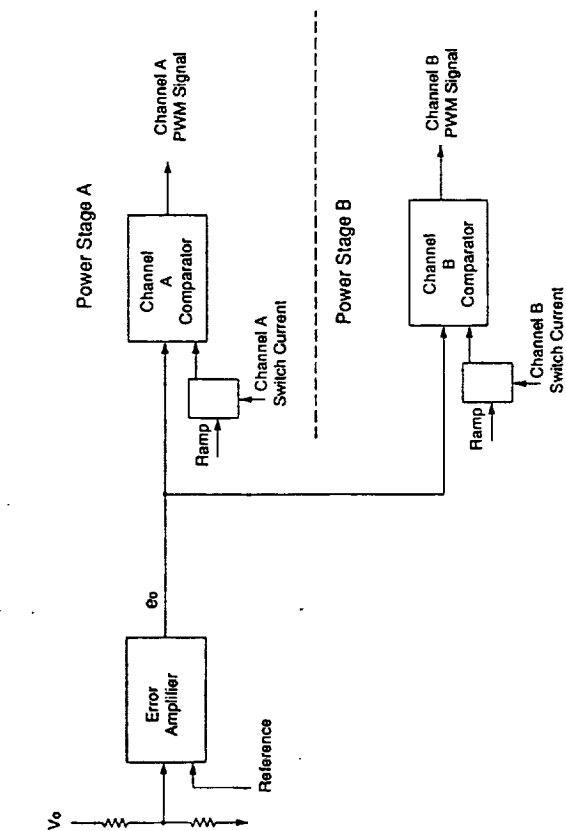
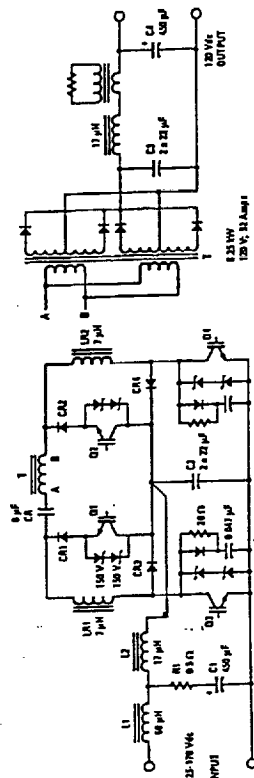
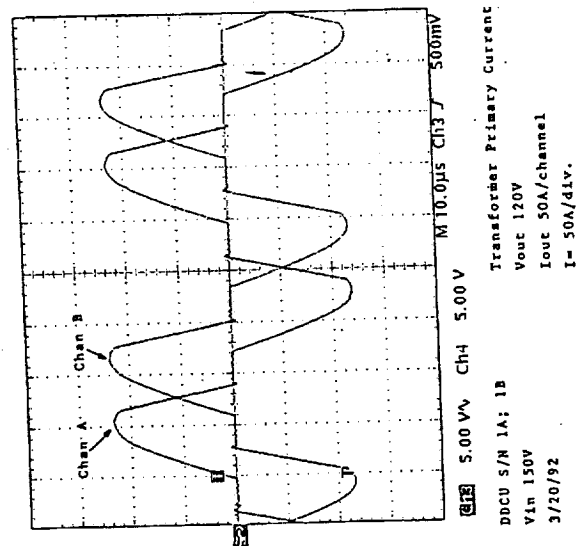


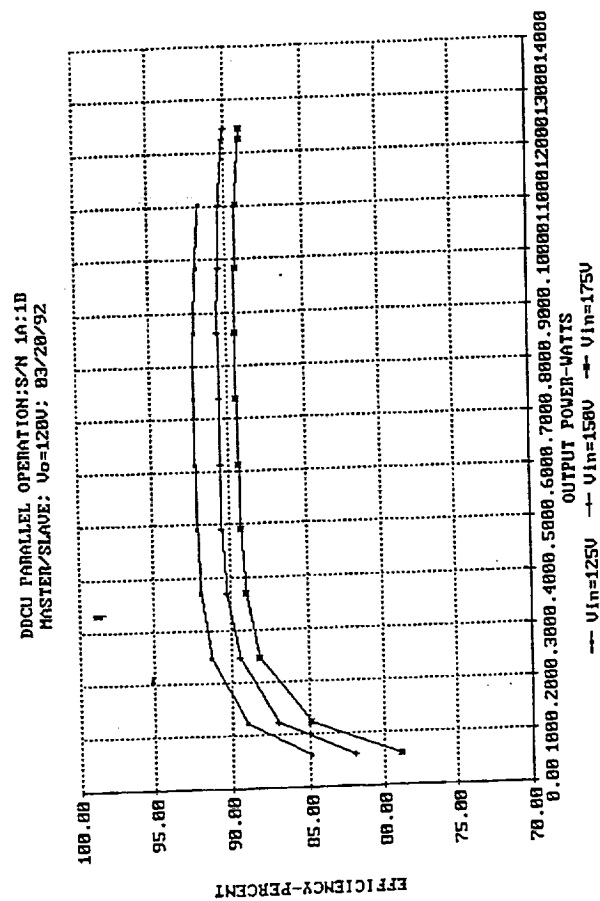
Figure 1. DC-DC Converter Block Diagram



**Figure 4. Current Mode Master/Slave Control**



**Figure 2. Series Resonant Inverter Power Stage Schematic**



**Figure 3. DDCU Efficiency (Two - 6.25 kW Units in Parallel)**

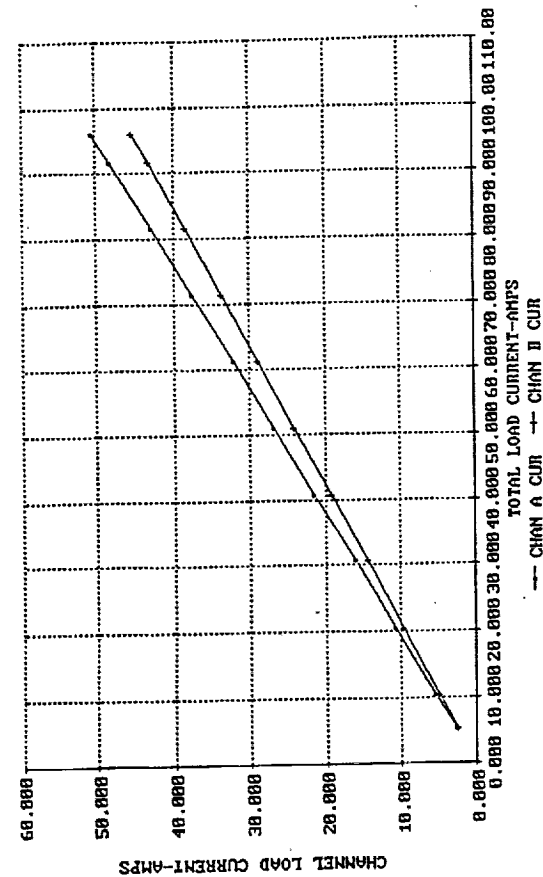


Figure 8. Current Mode Proportional Adjustment Control:  
Channel A - 100%, Channel B - 90%

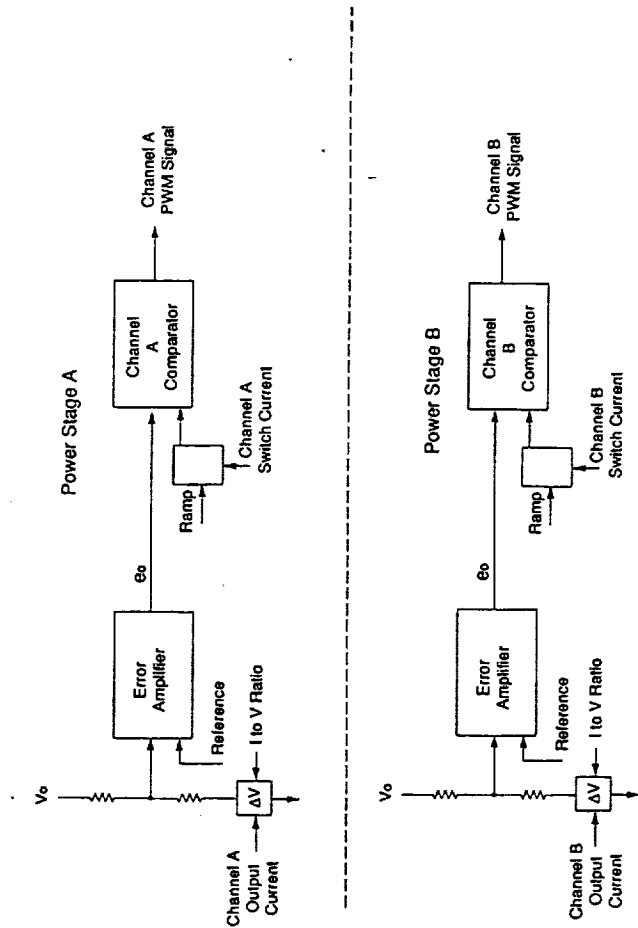


Figure 9. Droop Mode Control

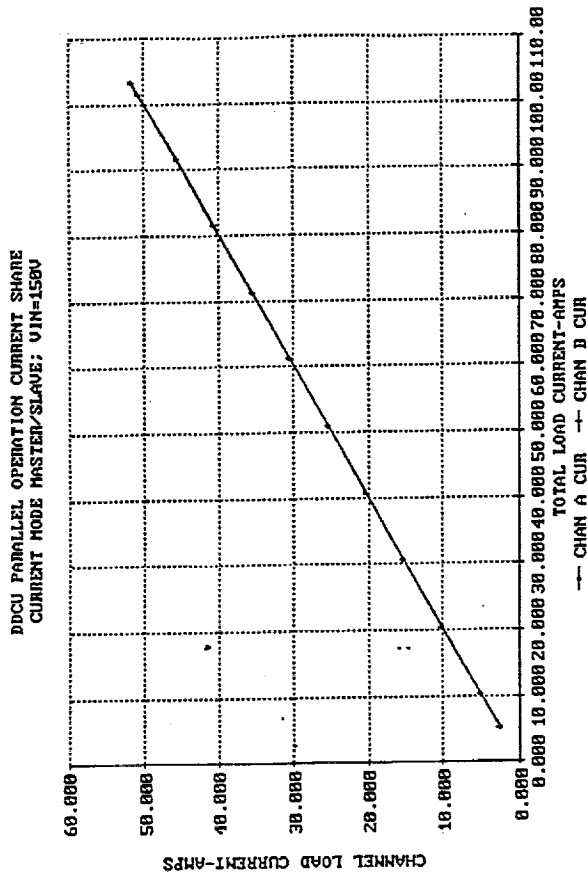


Figure 6. Current Mode Master/Slave Control - Current Sharing

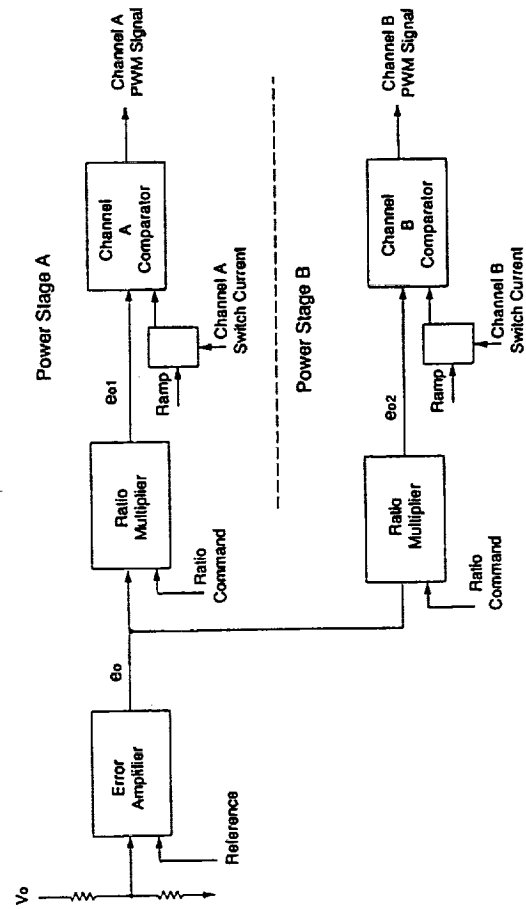


Figure 7. Current Mode Proportional Adjustment Control

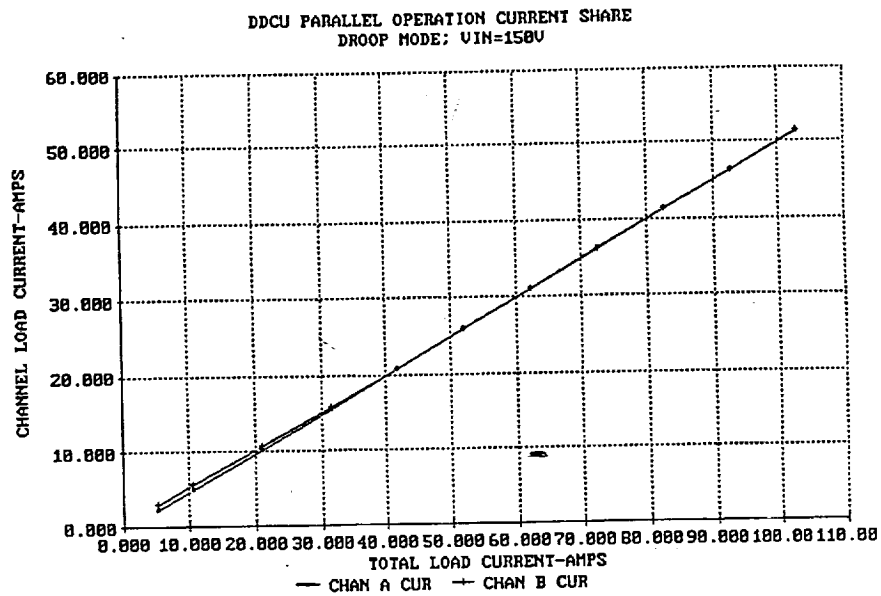


Figure 10. Droop Mode Control, Equal Current Sharing

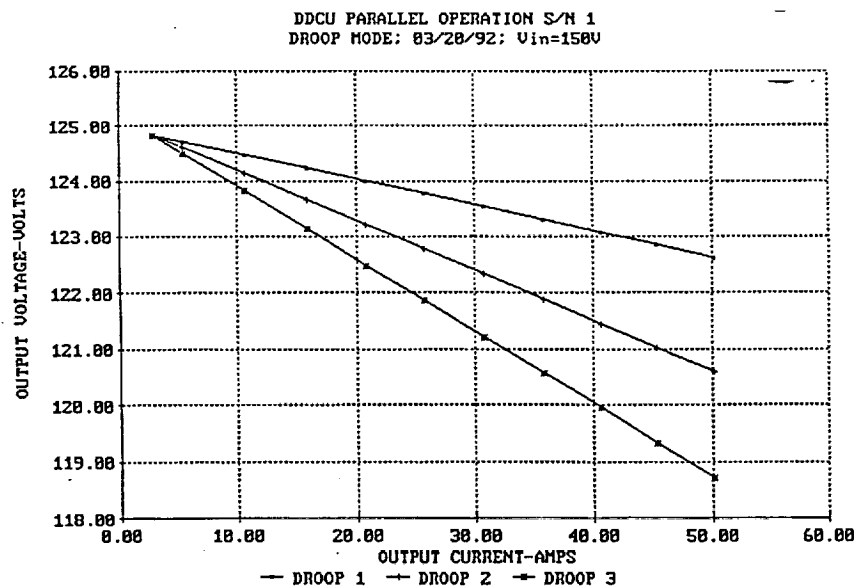


Figure 11. Droop Mode Control, Unequal Current Sharing

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