Current sharing becomes an important consideration when power architects parallel multiple power supplies or converters to increase output power or provide fault tolerance. Most current-sharing schemes employed with power converters involve either artificially increasing the output impedance of the converter module or actually sensing each output current, forcing all of the currents to be equal by feedback control. In a synchronous current-sharing scheme, however, there is no need for having a current-sensing or current-measuring device on each module; nor is there a need to compromise load regulation by artificially increasing the output impedance.

Synchronous current sharing is possible only in converter topologies where the energy transferred per switching cycle is fixed. An example of such a topology would be Vicor’s zero-current switching, quasi-resonant, high-density DC-DC converters. In such a synchronous array, each module has the capability to assume control; that is, it constitutes a democratic array. The module that is in command transmits a pulse on a communications bus to which all other modules in the array synchronize.

The converter modules actually use this pulse for power sharing as explained further below. The pulsed signal on the parallel bus synchronizes the high-frequency switching of each converter. The parallel (PR) pin (see Figure 1) is a bi-directional port used to transmit and receive information between modules. If the lead module relinquishes control, a new module will transparently take command with no perturbation of the output bus.

A pulsed signal also gives designers the option to use capacitors or transformers between PR pins, providing DC-blocked coupling. Such coupling prevents certain failure modes internal to a single module from affecting the other modules in the array, thus providing an increased level of fault tolerance.

Use of a current-share bus transformer (see Figure 2) allows arrays of converter modules to share current when they are widely separated or operated from independent sources. Because the current-share signal is a pulsed signal, it can be transformer coupled. Transformer coupling this pulsed signal provides a high level of noise immunity while maintaining SELV isolation from the source. This is especially useful when board-to-board load sharing is required in redundant applications.

Synchronous current sharing eliminates the need for current-sensing or current-measuring devices on each module. Additional advantages of the synchronous current sharing architecture include no degradation of load regulation, excellent transient response, no loop-within-a-loop control problems, and, as stated earlier, a high degree of immunity from system noise.

The availability of synchronous current sharing in democratically controlled arrays offers power architects new opportunities to achieve simple, non-dissipative current-share control. It provides options that simplify current sharing and
eliminate the tradeoffs — such as the need to sense the current from each individual module and adjust each control voltage — as is the case with other current-sharing methods.

The theory of operation of such a parallel array can be described by using the simplified block diagram of Figure 3. The vertical dashed line in the middle of the figure separates the two converters. The following simplifications and assumptions are used:

- The forward ZCS converter has been simplified to a non-isolated buck, quasi-resonant switching cell.
- The output LC filter of each converter has been modeled as a constant current load.
- The secondary controller is identified by the \( V_{\text{ref}} \) and op amp blocks. (In a real world Maxi, Mini, and Micro converters, the output of the op amp drives a VCXO (voltage controlled oscillator) that transmits a modulated burst of pulses through an air core transformer from secondary to primary. The VCXO stage has been omitted here.)
- The primary controller is identified by the CTRL and DRIVER blocks: the CTRL block has one input, one output and one input / output port. The signal transmitted from op amp to CTRL input port is equivalent to the input / output port signal (PR bus).

Proportional load share is based upon the principle that during each cycle of the power conversion process, each converter stores a fixed amount of energy in the \( L_d/C_{\text{res}} \) resonant tank. If the two resonant tanks are identical and the input voltages are equal, they will both store the same amount of energy. If the pulse frequencies are the same, the output powers will be equal as well, and, since the output voltage is common for both converters, the output current will be shared equally.

In this topology, converters have the unique feature of PR bus arbitration: several converters operated in a redundant parallel array are synchronized to the switching frequency of a single converter to achieve load share. The synchronization frequency is automatically defaulted to the highest switching frequency transmitted on the PR bus by any single converter in the array. This is because after a power conversion cycle, the converter with the highest switching frequency will always generate a PR pulse before any other module in the array.

The highest switching frequency converter assumes the role of “talker” and all other converters in the array will assume the role of “listener”. Although each converter will retain its ability to generate PR pulses at the output of its secondary controller, if a synchronizing pulse is received by its primary controller first, the converter will synchronize on that PR bus frequency. In the event that the talker is lost (due to a failure, for instance), the entire array will synchronize on the next highest switching frequency of the remaining converters. This feature is valuable in arrays designed to achieve high levels of redundancy or fault tolerance.

By connecting the \( V_{\text{ref}} \) to secondary signal ground (-Sense), a designer can force Maxi, Mini, and Micro converters to operate as “slaves”. A slave unit requires an external PR signal in order to operate. While a listener retains the ability to regulate the output voltage at \( V_{\text{nom}} \) once the synchronizing PR signal is removed, a slave cannot regulate the output voltage when operated without a controlling unit. Connecting some units in an array as slaves can simplify system wiring as slave units do not require that the sense lines be connected to the load – slave units need only be locally sensed.