

Understanding SDR Requirements

WHEN LEGACY TRANSCEIVER ARCHITECTURES FALL SHORT, IMPLEMENTING RECONFIGURABILITY USING EMBEDDED SWITCHED FABRICS MAY BE YOUR MOST COMPELLING OPTION.

BY GORD FINLAY

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(SDR) systems require reconfigurability at both the chip level to support switching air-interface modes, and at the system level for reconfigurable dataflow. Here, an air-interface mode refers to a combination of duplexing, multiple-access, modulation, and error-coding and correction schemes. Vendors of programmable DSPs, FPGA logic, and mixed-signal devices have already delivered significant enhancements in the ability to

support multiple modes and multiple bands in an SDR system. DSP performance has increased from tens of million instructions per second (MIPS) to thousands of MIPS, FPGA devices now support densities in excess of one million gates, and analog-to-digital-converter (ADC) chips have greatly increased sampling rates and dynamic range. Yet, more work needs to be done to improve the connectivity and interoperability of these products. Reconfigurability at the system level requires that

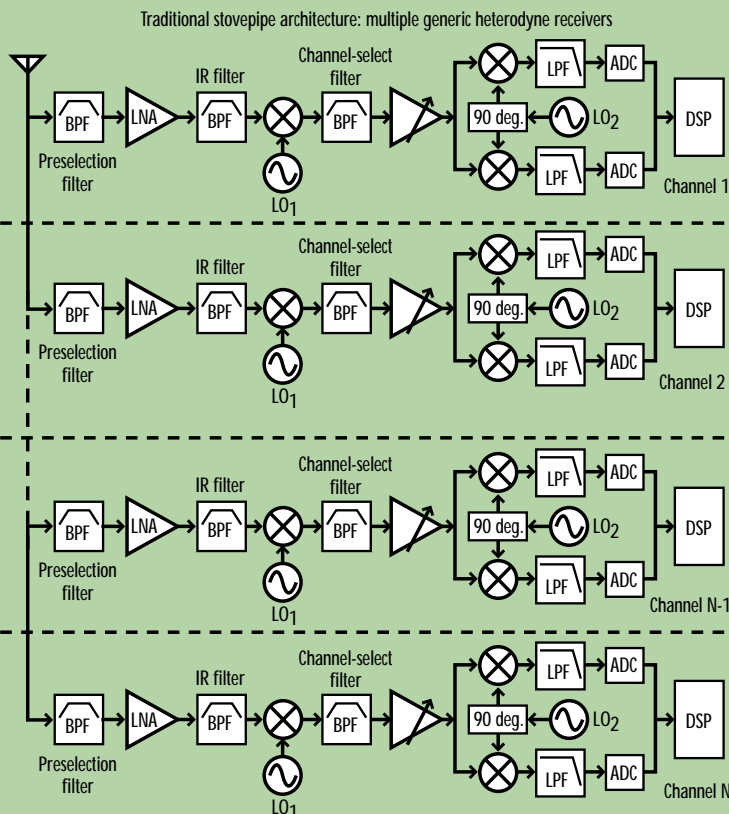
designers pay attention to the switching fabric of the system rather than just focusing on the chips that perform the physical-layer processing.

UNDERSTANDING SDR NEEDS

What is a software-defined radio? According to the SDR Forum (www.sdrforum.org), it is a collection of hardware and software technologies that enable reconfigurable system architectures for wireless networks and user terminals. SDR provides an efficient and comparatively inexpensive solution to the problem of building multi-mode, multi-band, multi-functional wireless devices that can be enhanced using software upgrades. It is applicable across a wide range of areas within the wireless industry.

Reconfigurability for an SDR can be “static” or “dynamic.” Static reconfigurability is the ability to reconfigure equipment capability ‘off-line’ (e.g., at supply), or via a smart card. Pseudo-static reconfigurability is the ability to reconfigure equipment capability over-the-air (OTA), while at the same time leaving it unchanged during a call. Dynamic reconfigurability, on the other hand, is the ability to auto-reconfigure equipment capability during a call.

Fundamental differences exist in the manner in which systems using SDR technology are implemented in the commercial, government, and military wireless-market segments. Wireless base stations for commercial cellular or personal-communications-services (PCS) services, for example, must handle heavy traffic volumes



1. The traditional stovepipe architecture, as pictured here, requires multiple generic heterodyne receivers.

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in a relatively restricted frequency range and support one or two air-interface modes with relatively infrequent system changes. By contrast, military tactical radio and battlefield radio applications involve a wide range of frequencies, many waveforms, software reloads on a minute-by-minute basis, rapidly changing co-site problems, and a very dynamic radio-frequency (RF) environment.

For a commercial base station, SDR requirements will vary depending on the user's position in the value chain. As such, the needs of the network operator are different to those of the original-equipment-manufacturer (OEM) base-station-equipment manufacturer.

In particular, a network operator needs SDR to:

- Maximize equipment longevity to minimize costs by deploying early without risking incapability with standards as they evolve.
- Deploy new services quickly.
- Optimize Quality of Service (QoS)

by dynamically modifying resource allocation to maintain desired QoS over radio channels.

• Provide flexible spectrum allocation.
A base-station equipment vendor, on the other hand, needs SDR to:

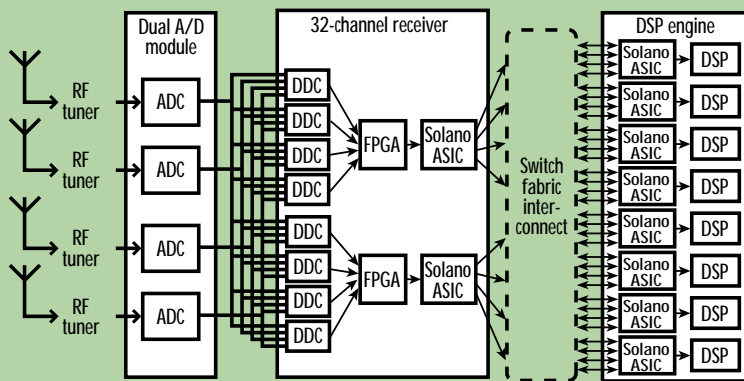
- Provide economies of scale. SDR provides for consolidation of product variants onto reconfigurable product platforms.
- Simplify bug fixes and software updates.
- Reduce time to market. Reconfigurable SDR reduces the amount of new intellectual property (IP) that needs to be created, maximizes the reuse of existing IP, and enables hardware/software co-design for reduced time to market.
- Facilitate adaptive-antenna support for third-generation (3G) technology. Support for smart-antenna subsystems on second-generation (2G) base stations is often implemented through use of a front-end appliqué to the existing equipment. However, this approach is infeasible for 3G base-station systems. Here,

adaptive-antenna functions need to be integrated into the digital intermediate-frequency (IF) and baseband-processing sections of the base station. An incremental deployment strategy is often used to add smart-antenna capability where it is most critical for expanding capacity or expanding site coverage. The use of SDR in 3G base stations enables deferred upgrade and deployment of smart-antenna capability in the field.

SDR can be used to provide dynamic reconfigurability to switch between multiple air-interface modes or personalities, but this will likely occur only in the handset and not in the base station. While dynamically reconfigurable SDR in the base station is technically feasible, radio-resource-management issues make it difficult to support dynamic switching between multiple air-interface modes. The main impediment to dynamic-mode switching in the base station is the difficulty in dynamically allocating channels or frequencies between several classes of mobile handsets, each

Table: Signal fabric processing options: advantages versus disadvantages

Interconnect	Advantages	Disadvantages
Direct-link-port connections	<ul style="list-style-type: none"> • Embedded into endpoint devices to minimize board space • Low-power dissipation • Deterministic and low end-to-end latencies between processing nodes 	<ul style="list-style-type: none"> • Too many different types of incompatible connections • Solution focuses on data streaming and ignores status and control flows • Lack of fully interconnected mesh • Intermediate endpoints need to provide pass-through routing or virtual channels for other devices
FIFOs	<ul style="list-style-type: none"> • Excellent bandwidth • Deterministic propagation delays 	<ul style="list-style-type: none"> • Fixed point-to-point dataflow (not reconfigurable) • Won't work across backplane—I/O logic needs proximity to the DSP resources • Requires a separate FIFO for each data stream
Bus transceivers	<ul style="list-style-type: none"> • Solves problem of moving data a fair distance over a backplane 	<ul style="list-style-type: none"> • Needs Glue Logic—Bus transceivers need significant support logic (e.g., FIFOs) if the data is to be moved at high speed or if each end must operate asynchronously
Embedded switch fabric	<ul style="list-style-type: none"> • Combines advantages of FIFOs and Bus Transceivers • Resistance to single-node failure • I/O doesn't need to be right beside the DSP • May provide separate paths for control flows • Lower cost than a full crossbar switch fabric • Minimizes heat dissipation and thermal problems (one half the number of link ports on endpoints when compared to a full crossbar) • Offloads need for DSP nodes to provide pass-through routing 	<ul style="list-style-type: none"> • Does not provide fully interconnected mesh between all nodes (DSP, FPGA, or downconverter devices) • Maintaining deterministic latencies can be challenging • For optimal performance and low power consumption, pairs of matching source and destination nodes with high peak dataflows should be made adjacent in topology for direct routing
Crossbar switch fabric (active backplane)	<ul style="list-style-type: none"> • Maximizes routing using fully interconnected mesh with any of M inputs routed to N outputs—useful for fully adaptive beamforming 	<ul style="list-style-type: none"> • Crossbar in active backplane becomes a single point of failure. This is an issue for high availability • Fully interconnected mesh is costly and an overkill for applications where beamforming is not required
Crossbar switch fabric (passive backplane)	<ul style="list-style-type: none"> • Maximizes routing—fully interconnected mesh with any of M inputs routed to N outputs 	<ul style="list-style-type: none"> • Fully interconnected mesh is costly and an overkill for applications where beamforming is not required • Costly—requires extra backup switch fabric cards for fault tolerance



2. A narrowband radio system with switch fabric interconnect is shown here.

supporting a separate and distinct air-interface. For a roaming user with a multi-mode handset employing SDR the handset only has to support one air-interface and frequency assignment at a time.

One area where SDR may encounter increasing popularity for dynamic reconfigurability is to support 2G and 3G packet data air interfaces that use adaptive-modulation and adaptive-convolutional encoding as well as forward-error-correction (FEC) schemes. The Internet is driving the demand for increased capacity and variable data rates for a broad range of services that extend beyond the currently deployed voice-only services. New packet data services for mobile wireless must be capable of supporting different QoS levels for different users and for different multimedia applications.

Some systems employing rate adaptation include 1xEV (HDR), general-packet radio service (GPRS), EGPRS, and time-division multiple access (TDMA) 136+. These packet-data services support dynamic switching on a frame-by-frame basis between several modulations and coding schemes assigned to users in different timeslots. For instance, 1xEV (on the forward link) supports 12 different data rates from 38.4 to 2457.6 kb/s. Differing rates may be used depending on the desired QoS as well as the level of channel impairment. Each data rate uses one of quadrature-phase-shift-keying (QPSK), 8-PSK, or 16-QAM modulations with either a rate 1/5 or rate 1/3 convolutional coder. A base station implemented with SDR can support dynamic modulation and coding schemes easily, and adds the potential for quick software upgrades to support new rates with different modulations (e.g., 64-QAM).

To date, SDR has had limited success in 2G deployments. However, 3G base-

station-equipment vendors are expected to supply SDR-equipped base stations that provide some static reconfigurability for ease of upgrade and to allow platform reuse. For packet-data air interfaces that use adaptive modulation and coding, economic factors will ultimately determine whether SDR will use programmable DSP with reconfigurable FPGAs or multiple function-specific ASICs to support dynamic-link adaptation.

With regard to the military tactical radio, SDR requirements are especially challenging. Here, air interfaces used by SDR are typically more complex than modes used in the civilian sector. The Operational Requirements Document (ORD) for the US Joint Tactical Radio System (JTRS) includes a set of requirements that highlights this point. Some of these requirements include:

- **Dynamic Reconfigurability.** JTRS terminals must support dynamic loading of any one of over 30 different air interfaces or waveforms identified in the specification.

- **Broad Spectrum Coverage.** JTRS must also support waveforms across a wide range of radio frequencies, from 2 MHz to 2 GHz, with the additional ability to add support for any military and commercial satellite and terrestrial communications above 2 GHz.

- **Low Probability of Intercept (LPI).**

- **Interference Mitigation.** Tactical radio systems must deal with serious co-site interference and electromagnetic-interference (EMI) problems when attempting to receive low signal-to-noise-ratio signals.

- **Adoption of open-systems architectures.** An example is the Software Communications Architecture (SCA), which has well-defined publicly available interfaces, and is supported by consensus-based standards. SCA is currently being

integrated into guidelines of the SDR Forum.

Support for static reconfigurability is the least common denominator for software-radio-platform capabilities in both military and commercial markets. Support for pseudo-static or even dynamic-mode switching is really only a requirement of military tactical radio systems or surveillance radio platforms. However, even platforms that support static reconfigurability (reconfiguring equipment capability 'off-line') must be flexible enough to eliminate system bottlenecks.

LEGACY ARCHITECTURES

Legacy-transceiver architectures for base station's employing transceiver (TRX) units with fixed-function IF channelizer modules and baseband engines suffer from a number of problems. Figure 1 illustrates a typical "stovepipe-style" system with N independent heterodyne receivers.

There are a number of limitations to conventional "stovepipe" architectures. The first is inflexible allocation of DSP resources. Stovepipe architectures lack the flexibility to change the system dataflow to support multiple bandwidths in the RF/IF front end and multiple modem types at baseband. Therefore, a separate TRX module is required for each air-interface standard. Another limitation is the lack of any economies of scale. Infrastructure manufacturers must create a new IF and baseband platform every time standards change and evolve. Network operators face "forklift" upgrades or change-outs to upgrade system capability. Increased costs result from equipment providers who must support multiple platforms.

Lack of a migration path to 2.5G and 3G air interfaces is another limitation. Consider a base station system with a mix of Global System for Mobile Communications (GSM)/TRX modules and EDGE-GPRS TRX modules. This system does not allow for easy migration from GSM to EDGE since the allocation of TRX modules in the system is fixed. As the proportion of data traffic changes over time with increased customer adoption of high-data-rate (HDR) services, change-out of modules is required.

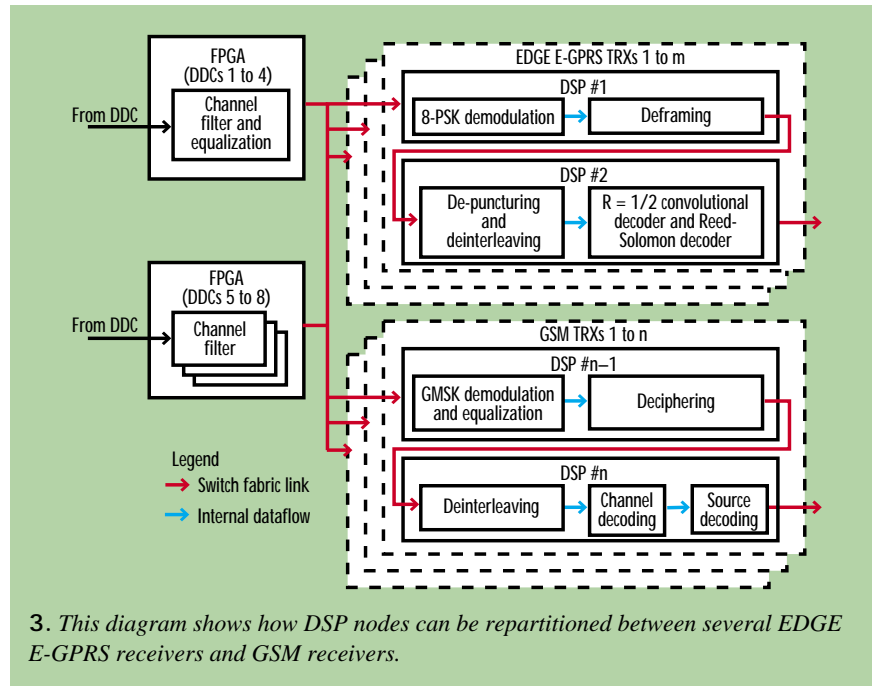
The key to constructing reconfigurability in the system dataflow for SDR transceiver systems is to adopt a design which provides enough flexibility to change the data flow for either narrowband or wideband tuner sections. The design would also need to allow data to

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be arbitrarily routed to any DSP node in a DSP resource cluster depending on the baseband modem algorithm to be used for the data channel. Additionally, a system-interconnect design should support high-bandwidth and deterministic low-latency data flow and scalability to allow adding DSP resources and channelizer cards without running into system bottlenecks. Partitioning of the channelizer and baseband-modem functionality across a backplane, as well as redundant channelizer and baseband DSP processing cards to eliminate any single points-of-failure will also be crucial.

The communication structure in a typical wireless transceiver is made up of multiple components. These include the RF fabric, the signal-processing fabric, the control fabric, and the network interface or LAN fabric (Ethernet/ATM). There is a lot of effort in the industry to create standards for the control and LAN fabrics but little to address the RF and signal-processing fabrics.

Currently, there are a number of different approaches to address the signal-processing fabric. Each has its own advantages and disadvantages and must be



3. This diagram shows how DSP nodes can be repartitioned between several EDGE E-GPRS receivers and GSM receivers.

judged accordingly (see table). These approaches work to move potentially huge amounts of baseband data over a backplane between multiple upconverter/downconverter channelizer sections and DSP resource clusters used for baseband-modem processing. Some of

these options include:

- Direct Link Port Connections.* Here one device directly interfaces with another and doesn't need any interface logic (e.g., connecting the SHARC link port interface of a Greychip GC4014 digital downconverter directly to an

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Analog Devices SHARC DSP).

•*First In First Out (FIFO) Buffers.*

These IC devices are often used in signal processing to provide streaming data paths directly between the expansion bus of a DSP processor and I/O modules.

•*Bus Transceivers.* These devices convert a parallel signal (like an analog-to-digital [A/D] output) to a more robust signal that can be transmitted between boards. As an example, low-voltage-dif-

ferential-signaling (LVDS) parts can be used to move digitized IF signals from an A/D converter board to a channelizer board.

•*Embedded Switch Fabric.* This defines a distributed switch fabric on an ASIC, which supports multiple link-port inputs and outputs. It allows local connections between signal-processing endpoints without the necessity of routing traffic through a centralized switch. The

Solano ASIC from Spectrum Signal Processing is an example of just such a fabric. It can communicate between high-performance DSPs, reduced-instruction-set-computer (RISC) processors, coprocessors, and FPGAs in an SDR system (Fig. 2).

•*Crossbar Switch Fabric (MxN) on an Active Backplane.* This defines a centralized cross-connect embedded within an active backplane which allows any of M input channels to be mapped to any of N output channels.

•*Crossbar Switch Fabric Cards on a Passive Backplane.* Here, a centralized crossbar is implemented on a switching card that plugs into a passive backplane. Multiple processing-node cards and I/O cards can be connected via the backplane in a "star" configuration to a MxN crossbar located on this switching card.

The major benefit of the embedded switch fabric approach is the ability to repartition the resource assignment in a receiver design. DSP nodes can be dedicated to different baseband algorithms and the dataflow can be configured accordingly. Figure 3 shows an example of partitioning DSP nodes between baseband pipelines for N EDGE E-GPRS receivers and M GSM receivers. With software upgrades or a change in the number of users allotted to EDGE and GSM respectively, the receivers can be statically reconfigured by reallocating algorithms to DSP nodes and modifying the routing of the dataflow over the switch fabric interconnect.

THE BOTTOM LINE

Given the uncertainty in the evolution of wireless standards and in the demand for various air-interface modes and rate classes, it is difficult to predict accurately how to partition resources in a system. Traditional "stovepipe" architectures lack the flexibility to adapt to newer standards or to change the relative proportion of TRX transceiver channel modules within a base-station system without change-outs. In an architecture that provides for system-level dataflow reconfigurability as well as reconfigurable processing elements, the system design is future-proof in the face of these uncertainties. *WSD*

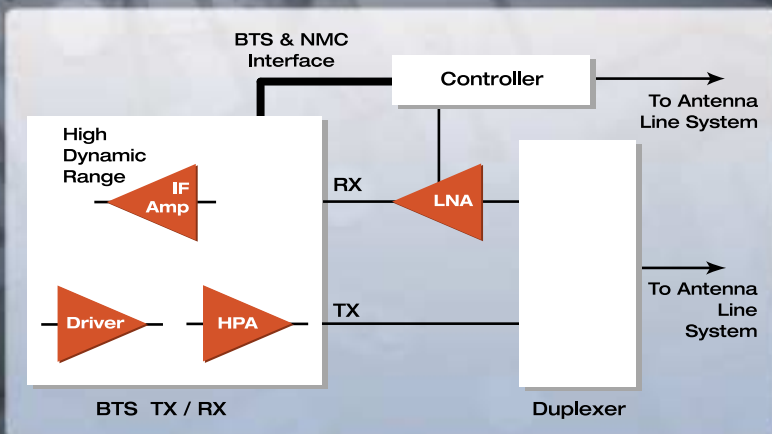
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