Multi-Band RF Front End for Software Defined Radio Applications

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Introduction:
With effective RF signal conversion, a bandpass RF communication signal may be converted to/from an intermediate frequency (IF) and then transmitted in a Software Defined Radio (SDR). The power and speed of digital signal processing (DSP) enables users to employ advanced communication techniques with the added benefit of "on-the-fly" programmability for repurposing in multiple applications. Innovative custom Monolithic Microwave Integrated Circuit (MMIC) RF front end and signal conversion developments by ViaSat extend SDR innovations and capability for multi-band applications.

This innovative custom RF front end capability includes a newly developed broadband Downconverter (DICON) and Upconverter (UCICON) for space applications, supporting a double balanced mixer with superior image rejection in a single device. The MMICs support multiple frequency bands from 400 MHz to 18 GHz for space communications and offer the potential of a miniaturized module of comparable integration level for signal conversion ideal for supporting SDR capabilities where size and weight are at a premium.

UCON/DICON MMIC Design Architecture:
The UCON and DICON utilize a double balanced mixer design with image rejection on a GaAs MMIC architecture, enabling mixer performance for broadband TV/RFX front end applications. Key MMIC elements include LO quadrature generation for low and high band operation, an intermediate frequency poly phase filter, a compact mixer core, and mixer gate bias voltage.

The UCON and DICON operate from 0.4 to 18 GHz and employ two different circuits to support low-band operation (0.4 – 8.5 GHz) and high-band operation (8.5 – 18 GHz) of the mixer. A master-slave flip-flop digital divider shown below enables wideband LO quadrature generation from 1 to 9 GHz, and a large coupler performs the same function for the high-band operation. Separating the LO quadrature generation within its operating range up to 18 GHz, the circuit elements enables the best performing circuitry to be used for the application.

A poly phase filter handles the intermediate frequency in a quadrature signal format, and along with the quadrature LO, enables unwanted signal cancellation. The UCON MMIC Block Diagram is shown, but the DICON MMIC operates the same way with RF/IF signal flow in the opposite direction.

Signal Conversion Fundamentals:
Signal conversion is a process used to convert a signal to a usable frequency for the application of the modulated/demodulated information necessary in the communication process. The process uses a mixer as a mathematical multiplier of two input signals to perform the conversion. One signal is a reference sinusoid produced by a local oscillator (LO) and is used to convert a bandpass signal to an intermediate frequency (IF) (in the case of down conversion) or to an RF frequency (in the case of up conversion). The drawback of performing signal conversion is the generation of additional frequency components which are a byproduct of the process and adversely affect communication performance. A mixer has the added benefit of limiting the intermodulation products produced by a standard single mixer.

Image Rejection Capability:
By carefully balancing the amplitude and phase response of the input signals, image signal cancellation may be effectively employed providing broadband image rejection for 400 MHz as shown by analysis and demonstration in the development of the UCON and DICON MMICs. In addition to creating amplitude and phase balance in the active integrated circuits, precise symmetry must be implemented throughout the MMIC design to ensure that phase balance is maintained. At 18 GHz a 15 µm difference in symmetry represents a full degree of phase imbalance.

Measured Performance:
The mixer gate bias voltage in the Mixer Core Architecture is adjusted to provide optimal mixer performance from 400 MHz to 18 GHz. Measurements on the MMIC have been made demonstrating the ability of the circuit to reject the image signal while maintaining good mixer conversion gain and minimal LO leakage. The operating frequencies between 6.5 and 9.5 GHz are an overlap region where the MMIC is capable of functioning in either low-band or high-band mode. The user can choose the best frequency threshold for low/high band operation based on measured results and application requirements.

The measurement data shown was taken in the interest of supporting the full 400 MHz to 18 GHz operating range. Depending on the application supporting specific frequencies or bandwidths of interest, the mixer gate voltage can be adjusted to give better amplitude and phase balance providing better performance than what is measured here.

The performance of the UCON and DICON MMICs enables a highly integrated broadband single conversion RF front end architecture with exceptional signal integrity.

Space Communication Applications:
Typical spacecraft (SC) communication subsystem includes a Telemetry, Tracking, & Command (TT&C) link for space vehicle command and control (C2) from a mission control center to a high rate data downlink for transmitting mission data to a mission/payload operation center. Depending on the mission’s communication subsystems may require redundancy in their system or require support for multiple C2 and/or mission data downlinks making them large, complex, and expensive.

The incorporation of a tightly integrated high performance multi-band RF front end in a single device opens up the possibility of extending SDR capabilities to include multi-use applications. Multiple mission communication link requirements may be met by a single component substantially decreasing the size and cost of typical spacecraft communication subsystem architectures.

In the typical SmallSat application where C2 and mission data are handled by separate components, employing the multi-band RF front end and a multi-application SDR, the mission communication need can be met by a single component. The Multi-Band Communications Architecture is capable of supporting any number of communication links within its operating range up to 18 GHz. Supporting multiple links simultaneously is also a possibility by adding DICON/UCICON D modules as needed for the system and may be easily architectured to provide redundancy by adding a switch matrix.

The space application DCON and UCON RF front end development includes a local oscillator (LO) designed to support space communication frequencies up to the Ku Band. More elaborate architectures have been developed supporting multiple LO’s along with a Switch matrix to support multiple (C2) link signals, making the system even more attractive in terms of redundancy. Application specific switchable filter preselection is also available in the UCON/DICON modules enabling specific communication link requirements to be met for a particular system without external filtering. A digital control interface provides a seamless subsystem control of these components.

Conclusions:
Communication applications are well suited for the versatile UCON/DCON RF front end where signal integrity and operational flexibility are highly sought. And the integration level for this component development is also highly suitable for cubeSat or smallsat system level integration.

The additional application of the SDR has the potential to fully leverage the highly integrated multi-band capability of the UCON/DICON capable of supporting multiple communication link requirements with a single component, providing a potential cost, size, and weight reduction to existing satellite communication link solutions.

Additionally, with high signal integrity and SDR flexibility virtually any data link protocol (within the Nyquist sampling rate capability) can be supported including advanced communication concepts exercising modern bandwidth efficient modulation techniques.