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Issues Related to Pulsed-DC, –RF, and Modulated Signal Operation using the AARTS System

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Accel-RF Corporation specializes in the design, development, manufacture, and sales of accelerated life-test/burn-in test systems for RF and Microwave semiconductor devices. This white paper describes technical information related to the AARTS Hardware. For more information contact:

Accel RF Corporation
10401 Roselle St. Suite 400
San Diego, CA 92121
(858) 332-0707

www.accelrf.com

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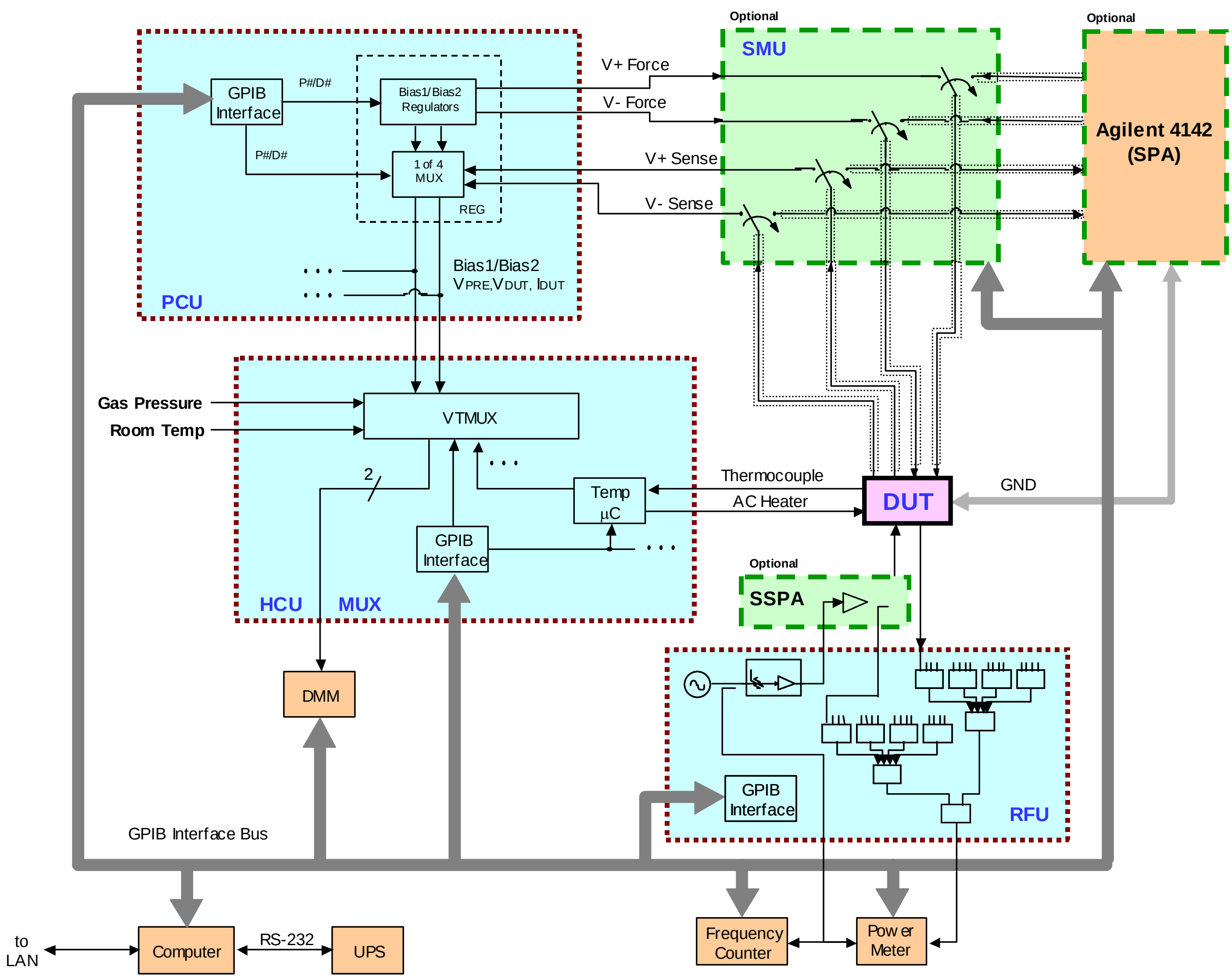
1 Description

A number of customers have expressed interest in using the AARTS system to generate non-CW DC- and RF-stimulus operating conditions. Specifically, this includes pulsed DC- and/or RF-drive signals, as well as modulating the RF stimulus with amplitude and/or phase control (e.g. to create a CDMA waveform). The AARTS system is designed to support arbitrary modulation requirements, constrained within certain limitations. The system is not designed as a pulsed-stimulus system; however, there are methods available that can support limited pulsed-stimulus scenarios. This document describes the techniques that could be employed and key issues related to implementation of these modes of operation.

Two primary areas to consider are: 1) measurement limitations; and 2) source limitations. Figure 1 presents a block diagram of the AARTS functional interconnects. The Power Control Unit (PCU) provides DC stimulus, and the RF Control Unit (RFU) provides RF stimulus. The optional Semiconductor Parameter Analyzer (SPA) can of course generate pulsed waveforms, but it may only drive one DUT at a time for special-purpose measurements. The primary DC stimulus is supplied by the continuous voltage/current sources located in the PCU.

Figure 1: AARTS Functional Block Diagram



All RF stimulus is generated within the RFU. A common CW Voltage-Controlled Oscillator (VCO) provides a global frequency source. A Variable-Gain Amplifier (VGA) exists for each channel that supports swept RF power measurements (i.e. gain compression sweeps). An optional Solid State Power Amplifier (SSPA) may exist in the system if higher than the standard +15-dBm RF drive levels are required.

An additional complication exists if both RF and DC are to be pulsed in synchronization, such as when testing an RF MEMS switch that cannot support hot-switching. In these cases, DC must be applied prior to RF, and RF removed before DC.

RF- and DC-measurements are made by employing CW measurement instruments: 1) dual-head RF power meter (PM); 2) frequency counter (FC); and 3) digital voltmeter (DVM). The SPA is the only instrument that can induce and measure pulsed stimulus.

1.1 Pulsed Measurement Limitations

As shown in Figure 1, all channel parameters are measured using dedicated precision instruments; hence, avoiding accuracy/calibration issues related to the power supplies or RF sources. DC- and RF-switch multiplexer systems are employed to select and route the channel (or signal) of interest to the appropriate measurement device (PM, FC, or DVM).

The PM, FC, and DVM instruments all perform some type of averaging, typically related to power line cycles and measurement range, to yield results. Using a multiple of power line cycles allows the instruments to eliminate crosstalk effects from the main 50/60Hz AC power supply. The LifeTest program allows the user to specify the Number of Power Line Cycles (NPLC) used for DVM readings, but not PM or FC readings. Nevertheless, the PM and FC automatic settings also are tied to NPLC.

This raises a key point with regard to pulsed operation, or modulated stimulus. Since the only readings that these instruments acquire are "average" readings, as long as the pulse repetition rate (or modulation rate) are high enough that the meter is sensing an average power repetitively and repeatably over a measurement interval, then the power measured may be adjusted mathematically to convert from average power to peak pulsed power. For example, if 1-W is measured for a pulsed waveform power that has a 50% duty factor and a rep rate of >1kHz, then the peak power would be 2 W.

There are no capabilities in the current equipment for measuring pulsed performance, such as rise- and fall-times, overshoot, ringing, etc… However, there is an accessory port that could be used for certain RF pulsed-performance parameters (see RFU block diagram in Figure 3). User-defined external equipment could be incorporated and controlled under customer-generated software control. A token passing scheme is available in the software to allow efficient program and instrument management.

1.2 Pulsing DC Stimulus

The Power Control Unit (PCU) contains two supplies for each DUT channel: Bias1 is unipolar and can source up to 100 V and 3 A, typically used as a drain or collector supply of a transistor; Bias2 is a bipolar source which can sink and source current in both polarities, designed to supply a gate or base voltage or current. The upper portion of Figure 2 shows the Bias1 switching power supply and the lower part the Bias2 linear supply. As shown, there exist series and shunt switches for each supply. The series switch engages the supply to the load. The shunt switch operates in complementary synchronization with the series switch for the purpose of rapidly discharging energy that may be in the fixture capacitance and device junctions. Its intent is to save the device from catastrophic damage in a thermal-runaway scenario.

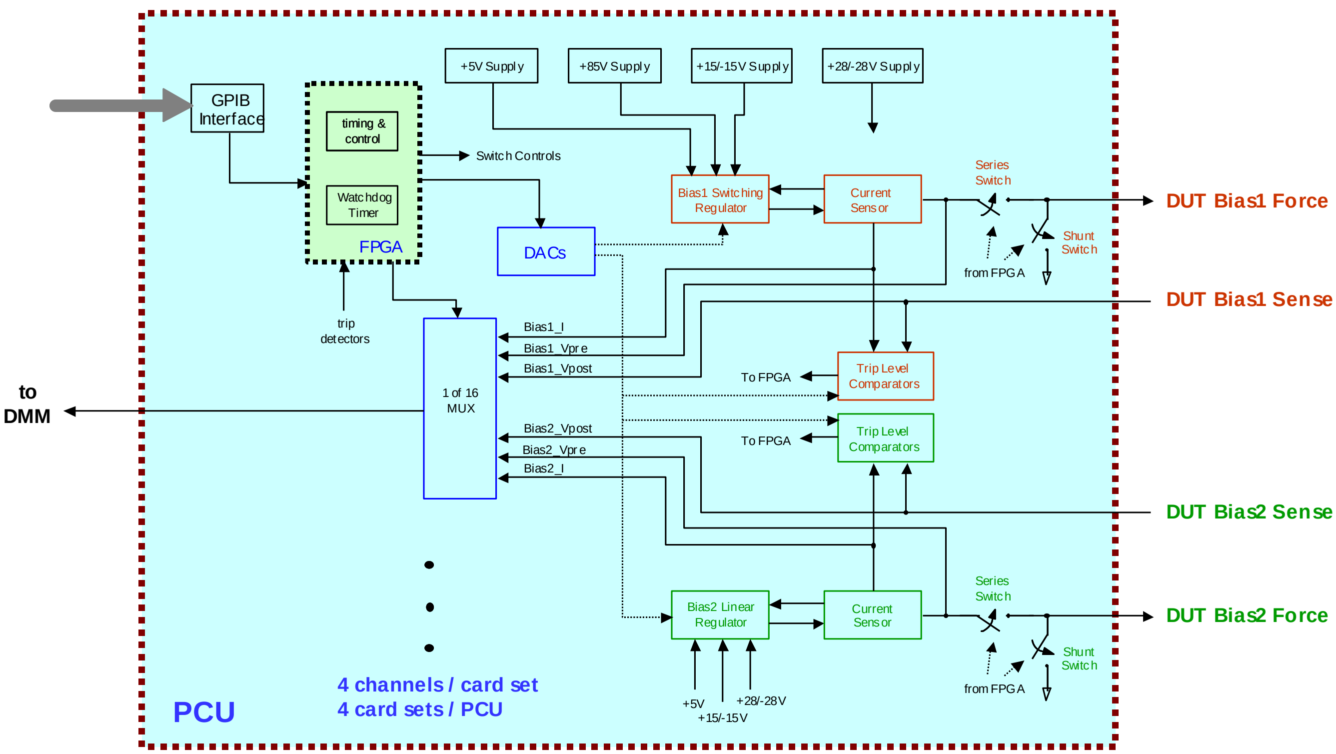
The series and shunt switches employ HEXFET technology, so they are safe to perform hot-switching. However, there are several mitigating factors related to switching speeds of the series/shunt switch configurations. First, the Bias1 and Bias2 outputs comprise HEXFET switches, each with associated gate-source capacitances that must be charged/discharged. Second, the shunt switch operates in complement to the series switch. Without the shunt switch, any charge storage at the DUT will remain charged after the series switch opens unless there is some kind of bleeder circuit included at the load. Third, the cabling in the system introduces additional series inductance/resistance and a small amount of capacitance. Hence, actual rise/fall times at the fixture will depend on what the supplies themselves can source through the cabling.

The series/shunt switch timings cannot overlap without inducing ground currents during the time at which both are ON. The timing between these two functions for both startup and shutdown delays may be set through software (valid values: <1us to >8ms). The system default is set at 1ms. This limits the maximum switching speed when using the internal power supply switches.

For both switches, the fall time (ON-to-OFF) is faster than the rise time (OFF-to-ON). Further, the Bias1 switch is slower than the Bias2 switch because of large gate-source capacitance in the HEXFET switches. Practically, the Bias1 series-switch rise-time ranges between ~10µs to 1ms, based on load conditions. The Bias1 fall time should be in the range of ~1µs to 100µs – also dependent on load conditions.

To achieve a reasonable relationship between known ON and OFF times (i.e. minimize rise/fall time effects), it is recommended that a period on the order of seconds and pulse width >10ms be maintained. Note that some software modifications would be required to implement this type of pulsed operation.

Figure 2: PCU Block Diagram



For those applications that require faster switching speeds, another alternative exists. First, note that the power-supply control-loop time constants are in the range of 10mS. Hence, any load variations that occur at a much faster modulation rate are effectively averaged out in the supply, and source effects are minimal. Since the measurement process and power-supply source process are long-lived with respect to switching rates >1kHz, it is possible to implement a switching circuit in the fixture that can provide pulsed operation to the device. Implementing the switch at the fixture eliminates the stray capacitive/inductive low-pass filter effects of the system cabling. Hence, clean switch performance is more easily achieved. The difficulty is in how to control the switch remotely from the computer (i.e. changing duty factor, repetition rate, etc…).

The LifeTest software could be modified to accommodate pulsed-to-average reading corrections, and that may satisfy the most basic pulsed operating requirements. However, in some cases it might be desirable to support the programmability feature and/or disable pulsed-DC operation either permanently or temporarily.

Several approaches could support fixture switching. First, an external pulse generator could provide global control for all DUTs. If it were programmable the computer could control repetition rate and pulse width. However, it would not be feasible to disable pulsing to make CW measurements on a per-channel basis.

The second approach requires each channel to provide the pulse signal. Each PCU power supply card includes a Field-Programmable Gate Array (FPGA), used to generate all on-board glue-logic functions. There should be enough room in the FPGA to support addition of a counter that could be used to generate the pulse signal over a wide range of settings. Implementing this control in the FPGA yields independent per-channel control. The system harness assembly could be modified to route this pulse signal from the PCU to each DUT. This would allow both independent programmability of the control and ability to locally disable pulsing for CW measurements to each individual DUT if desired. However, maximum switch rates would be limited by the dynamics of the source/load impedances.

A third approach relies on a free-running oscillator at the fixture, which generates the pulsing waveform locally, and the spare line in the PCU card/harness assembly provides a simplistic gating function. This allows the software to temporarily disable the pulsing while taking measurements, and re-enabling it afterward.

1.3 Pulsing & Modulation of RF Stimulus

A block diagram of the RF Control Unit (RFU) is presented in Figure 3. One of two Voltage-Controlled Oscillators (VCOs) is used to generate a single global frequency for the test set. As shown, the output is routed out of the box and back into the RFU via a horseshoe type connection. Note that a Variable-Gain Amplifier (VGA) is dedicated to each of eight channels. This supports some control over the maximum DUT drive levels. Individual VGAs are dedicated to each channel for gain-compression sweeps. Finally, an optional SSPA (one for each channel) may be employed for higher-power applications.

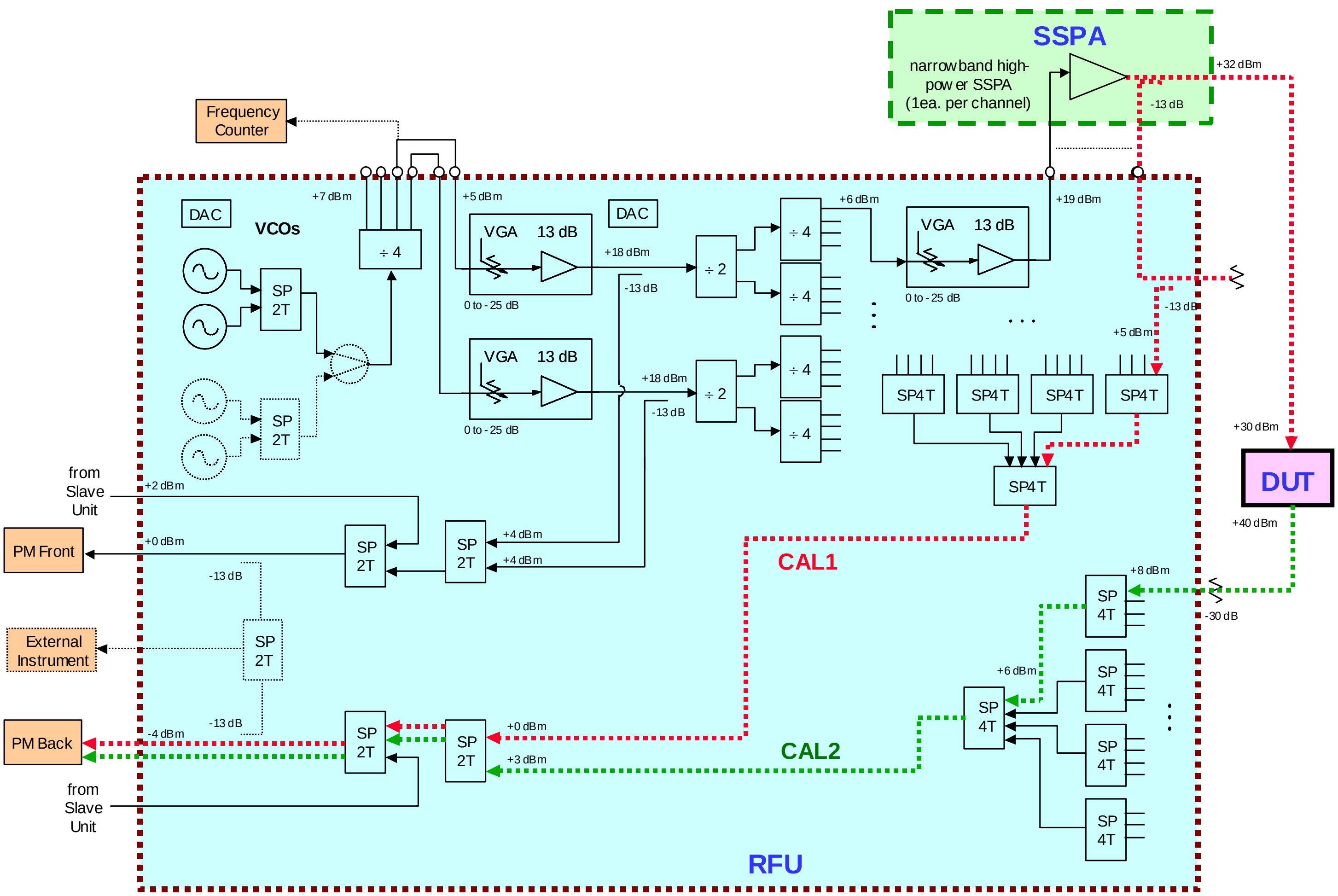
As designed, the system routes the various signals to the measurement devices based on computer control. The instruments are all CW based, but are capable of limited pulse discrimination, subject to the caveats mentioned in Section 1.1. The external horseshoe cable is provided as a port in which external modulation may be applied, such as a CDMA waveform. The software also supports injection of an independent frequency source into the RFU inputs if multiple frequency-tests are desired. Hence, independent control of groups of eight channels is possible, based on user preference.

How does the system respond to modulation? Given that the RF power meter is an average reading device, modulation that is rapid enough to appear constant over the PM averaging cycle is transparent. Factors such as AM-pulsed RF signal sources would have to be compensated by the user. The VGAs, power dividers, couplers, switches, etc. are broadband devices; hence, bandwidth distortion effects should be quite minimal. However, the SSPA is a narrow-band device, which could affect signal integrity based on the relation of SSPA bandwidth to modulation rate. In practice, the bandwidth of the SSPA is much greater than that of typically required modulation rates. Hence, signal distortion caused by bandwidth effects are minimal.

Amplifier dynamic range could also affect modulation integrity. To minimize compression effects on the RF waveform, the maximum drive level could be decreased to provide greater dynamic headroom. Realistically, the system is not being used to measure high-performance characteristics, such as Bit Error Rate; hence, dynamic range effects are of limited impact.

A larger issue, related to pulsed performance, is where and how that modulation is applied. If global pulsing is adequate, and no synchronization between DC and RF is required, then applying the modulation in the horseshoe cable provides a convenient single-point injection. This also allows the calibration factors to be unaffected by the RF switch gating.

Figure 3: RFU Block Diagram



If independent control of RF pulsing is required and/or synchronization with a pulsed-DC signal is important, then the RF switch must be collocated at the DUT with the DC switch. Implementing such a control circuit is not extremely difficult, but it generates some issues with the RF calibration concept. Note that the Cal1 factor represents a relative loss between the transmitted signal impinging upon the DUT input as compared to a sample of the transmitted signal routed through the RF switch matrix. The assumption is that this loss is not dependent on power level and is stable with time. If a switch is placed at the DUT, it must first support the intended maximum source drive level. At a 5-W drive level, a very robust switch would be required. Second, it must be capable of being hot-switched, a problem for many switch technologies. Additionally, for high-power switches low-loss, long-term stability can sometimes be a problem.

Given that these issues may be overcome (or are insignificant with respect to the device performance degradation expected) then RF- and DC-pulsing are indeed possible, even in synchronization. The RF fixtures typically have just enough room to fit a companion circuit board with HEXFET switches for DC switching, and associated control circuitry. The RF switches would need to be incorporated into the matching-circuit area. This could be challenging but should be practical for medium-power switches. Larger high-power switches may require some ingenuity to incorporate into the fixture assembly, but nevertheless is possible.

2 Summary

This discussion has detailed the issues related to practical implementation of modulation and pulsed-stimulus capabilities in the Accel-RF AARTS product family of test instruments. Implementation difficulties are driven by requirements such as pulse repetition rate, pulse width, accuracy requirements, etc… Consideration should be given to global versus individual independent control, synchronized RF- and DC-switching requirements, and other factors required by the specific test application. Based on the requirements of the test, implementation may include a software only modification, hardware configuration and software modification, and/or additional hardware to be developed and purchased such as embedded fixtures, RF- and DC-switching components, etc…

Finally, modifications required for measuring dynamic switch performance parameters, such as rise- and fall-times, overshoot, inner pulse power droop, etc… would necessitate user created and controlled external equipment employed via a token-passing control paradigm to support such extended capability.

Users interested in incorporating these capabilities into existing equipment or equipment to be ordered should consult Accel-RF for further discussion of requirements and possible solutions.

For technical questions or comments related to the information contained in this paper please contact David Sanderlin at rds@accelrf.com. For information about Accel-RF Corporation or any of our products and services please contact Accel-RF at info@accelrf.com or visit our website at www.accelrf.com.