General Notes:

The 4 and 8 pack development is R+D. The LLRF system must be designed to allow flexibility in operational parameters, number of channels, etc.

It must be straightforward to add channels to the system

“Raw” RF signals must be available for measurement with oscilloscopes, spectrum analyzers, etc. Providing X-band, IF or IQ signals with >100MHz bandwidth is sufficient.

Calibration: The system must allow for calibration of selected channels to 0.2dB absolute, 0.1dB stability. Note that additional equipment may be used to provide calibration of these selected channels.

There must be either an analog input(s) or sufficient digital programming flexibility to allow arbitrary modulation of the RF with a 100MHz bandwidth. Providing analog inputs to an IQ modulator (or allowing the addition of an external IQ modulator) is sufficient.

X-band cables have been a continuous source of problems. If X-band signals are to be transmitted over long distances, an engineering solution to the connector problem is required.

Adjustable X-band frequency control +/- 30MHz is required for some tests.

Possible new specification: It should be possible to measure timing difference between the rising and falling edges of “related” RF signals (e.g.: structure in / structure out) to <1ns. This may have implications for IF frequencies, and for whether the IFs need to be locked to the master oscillator.

RF Control: Each Klystron must have independent phase and amplitude (or I/Q, or digital IF) control. The control requirements are:

8 and 4 Pack overall requirements:

LLRF output power >10dBm.

LLRF output to be switchable in pulses with rise / fall times of <10ns to 10% power, and time delay < 100ns from hardware trigger.

LLRF output power to have an adjustable level with protection against sudden level changes. This could be implemented as an attenuator with a very slow (~second) attenuation control. This is to prevent suddenly applying high power to a structure after a trip.
4-Pack: 2 Klystrons to be controlled.

1. The signals to the 2 TWTs require independent slow (1 second time constant) phase and amplitude control. Stability ~5 degrees X-band. Accuracy: no tight requirements - will be controlled by measuring the output.

2. The phase of the LLRF signal to the 2 TWTs must be switched by 180 degrees with a switching time of less than 10ns (settle to 10 degree phase).

3. The output from the LLRF system must be switched in pulses with 10ns rise and fall times (to 10% power) and 50ns to 4 microsecond length. Two pulses are required, with the second pulse starting at the time of the phase switch. This is to allow operation with shorter RF pulse lengths.

8-Pack: 8 Klystrons to be controlled.

1. The signals to the 8 TWTs require phase and amplitude control in 8 steps of ~400nsec each. I/Q steps should settle to ~1% in ~10ns. Stability should be 8 bit.

2. An additional ~8 phase and amplitude ramps, each 50ns, may need to be applied to all of the drive signals to compensate for the turn-on of the modulator. This signal would be the same for all klystrons.

Note that 1 and 2 could be achieved with a 20MHz, 8 bit (true) DAC driving each of the Is and Qs for modulating the RF.

3. The output from the LLRF system must be switched in pulses with 10ns rise and fall times (to 1% power) and 50ns to 4 microsecond length. 8 pulses (of identical length) are required, spaced by ~400ns. This is to allow operation with shorter RF pulse lengths.

RF Diagnostics:

Diagnostic Types:

1. Calibration / Special Purpose Diagnostics: These are used to look at a small number of signals, but must be switchable to look at any RF signals. Real time readout is not required. Digital IF processing at 200 MHz bandwidth (100MHz minimum) to 8 bits is required. Digitization should occur on all pulses, with ability to store on a “breakdown” pulse. This can be performed with a >1Gs/s scope.

2. Waveform Diagnostics: 100MS/s, 8 bit digitization of I / Q signals for a selected number of channels. 200MS/s on a 50MHz IF digital down conversion is preferable. These signals should be recorded on every pulse, and read out on “breakdown” pulses. Note: #1 diagnostics could perform this function if price and data rate are reasonable.
3. Single Pulse Diagnostics: Data values are measured and stored on every pulse. Note: #2 diagnostics could be used if price and data rate are reasonable. The following should be measured on selected pulses.

- **Peak hold**: 50MHz bandwidth, 8 bit (commercial unit available from Analog Modules is probably adequate).

- **Rising Edge Time (TDC), Falling Edge Time (TDC)**: ~1ns resolution. Standard LeCroy or similar TDC is adequate.

- **Gated integral of I, Q**: 50MHz bandwidth, 8 bit. Standard LeCroy ADC or similar is adequate.

**Approximately Signal Counts.**

**Calibration / Special purpose (>1Gs/s Scope).**

4 pack or 8 pack: Any pair of signals should be available for measurement. Remote control of MUX strongly preferred to cable switching.

**Waveform Diagnostics:**

4 Pack: Klystron in (2), Klystron out (2), Klystron Reflected (2), Sled out (2), Test device in, Test device reflected, Test device out (3). Total 11.

8 Pack: Klystron out (8) Mode Launcher 1 out (4), Mode launcher 2 out (4), Mode launcher 2 reflected from waveguide (2). Total 18.

8 Pack with 6 structures: 8 Pack requirements + Structure in (6), Structure out (6), Structure reflected (6). Total 18. Total with 8-pack is 36.

**Pulse Diagnostics:**

4 Pack: TWT in (2), TWT out (2), TWT out reflected (2), Klystron out (2), Klystron out reflected (2), Sled Transmitted (2), Test device in, Test device out, Test device reflected (3) = 15 RF signals. Assume all 15 required Peak detect, or Gated Integrator. Approximately 10 signals required rising edge, falling edge (20 channels). Total 35 channels.

8 Pack: TWT in (8), TWT out (8), TWT out reflected (8), Klystron out (8), Klystron out reflected, Mode launcher 1 out (4), Mode launcher 1 reflected (4), Mode launcher 2 out(4), mode launcher 2 reflected (4), DLDS in, out, reflected, 2 modes (6). Total 54 RF signals. Approximately 20 signals will require rising edge and falling edge (40 channels). Total 94 channels.
8Pack with 6 structures. Add 18 channels of Peak, Gated, Rising Edge, Falling Edge. Total 18 additional RF signals Total (108) channels. Grand total 72 RF signals, 202 channels.

NOTE: The channel counts refer to the number of different data points recorded, not to RF channels. The total number of RF channels is ~15 for 4 pack, 54 for 8-pack, 72 for 8-pack with 6 structures.