Protocol for assembly and testing of RF Joints in End Station B

Keith Jobe – March 28, 2007, Updated May 23, 2008

RF Safety Considerations:

Very Low power RF systems:

Milliwatt-class RF systems are used throughout the facility for measurement systems. These systems typically use detector diodes or mixers for the measurements and operate at less than 0.1 watt. These systems usually use cables and connectors which, due to their small size (size << wavelength) are very poor transmitters. Occasionally, waveguide systems are used (e.g.: network analyzers or mechanical filter networks). The users of open waveguide systems should recognize that much of the RF power can be released into the general laboratory environment.

The general and intuitive safety protocols of avoiding direct contact with the RF source and avoiding placing the connector or waveguide to your eye is recommended.

Low power RF systems:

Power systems greater than approximately one watt (or 1/5 watt average power for pulsed power systems) can create non-ionizing radiation hazards. These systems typically include RF distribution amplifiers.

Low power systems can be safely used if the following precautions are observed:

- Turn off amplifiers while connecting or servicing cables or loads.
- Examine cable terminations for structural integrity.
    - Specifically, if the shield connection on the coaxial cable is broken or loose, then the connector/cable assembly can become a very effective transmission antenna. Connectors must be in excellent condition for use with RF.
    - Care must be taken when designing test fixtures and equipment to avoid free-space radiation. For example, a piece of coaxial cable with the shield removed for the last ¼ wavelength is a very effective antenna that can turn a one-watt instrumentation amplifier into a non-ionizing radiation hazard.
- Label all RF power connections that leave the chassis with an appropriate warning label that includes the frequency and RF power levels. Note: When using a coupler or power tap-off device, only the high power leads need to be labeled for safety.
- If any waveguide systems are powered at greater than 1 watt (CW) or 0.2 watt (average pulsed), the protocols for high-power systems must be used.

High power RF systems:

For the purpose of this document, High Power systems start with the output of the klystron drive amplifier or traveling wave tube.

RF safety considerations are paramount when working on these systems. If there is any doubt regarding a design or the operation of a system, please contact the Project Manager, Safety Officer, or the chair of the Non-Ionizing Radiation Safety Citizens Committee.

As applicable, all high power systems must:

- Be locked off or secured in a manner consistent with the LOTO protocols used for electrical safety by the employee directly working on the systems.
- Prior to the opening of any RF system downstream of a klystron, the Project Manager (or a qualified colleague) must lock out the power source with an operations lock and an appropriate tag (including the reason for the lockout, name and date).

- All flanges, joints, gaskets, connectors must be carefully examined for damage or defects prior to assembly.
- Vacuum joints using metal-based vacuum seals must be vacuum-tight prior to operation. Special circumstances may exist where preliminary high-power testing is done prior to securing the vacuum – in these circumstances the protocols for non-vacuum joints must be followed.
- All accessible joints must be tested at a lower power level for RF leakage by a qualified tester. Metal-based vacuum joints are exempt, as are joints in accelerator tunnels (no access during operation) and joints positioned out of reach to personnel (e.g.: joints 10 or more feet above the working surfaces).
- The testing equipment must be demonstrated to be in working condition prior to use.

<u>Permissible Exposure Limits:</u>

The following table summarizes the permitted exposure limits in the End Station. Note these numbers represent the whole-body exposure (averaged) or the specific power level the eyes are exposed to. When estimating permitted emission from a point-like source (e.g.: a cable connector), allowances for connector-eye distance is permitted. For example, a 10 cm radius sphere has a surface area of about 1257 cm^2. Dividing this by a factor of 2 (to approximate field-patterns of radiation), this will allow a power leakage of approximately 628 times the values shown below. Note: this is why training specifically includes warnings against bringing connectors to near the eyes.

	CW Radiation	Average Pulsed RF (0.20 * CW)	Typical duty factor	Peak Pulsed RF Power @ duty factor
VHF 119 MHz 476 MHz	 1 mW/cm^2 1.6 mW/cm^2	 0.2 mW/cm^2 0.3 mW/cm^2		
L-band 1,300 MHz	4.3 mW/cm^2	0.87 mW/cm^2	$1 * 10^{-2}$	87 mW/cm^2
S-band 2,856 MHz	9.5 mW/cm^2	1.9 mW/cm^2	$1 * 10^{-5}$	190 W/cm^2
X-band 11,424	10 mW/cm^2	2 mW/cm^2	$2 * 10^{-4}$	10 W/cm^2

<u>Microwave emission detectors</u>

Calibrated RF power detectors appropriate for use in establishing safe working (Industrial Hygiene) conditions are available at SLAC. Many of the detectors use a broad-band thermal detector which is qualified for use with pulsed RF systems. Use care in selecting the detector to ensure that an amplified antenna system is not used with low duty-factor pulsed RF systems as the receiver can saturate and under-measure the radiation levels. All Industrial Hygiene detectors must be verified to be within their calibration timeframe prior to use.

Commercial detectors can be difficult to use as they are usually broad-band and will respond to a wide variety of external stimuli including fluorescent lamps, computer monitors, power supplies, and cell phones. Prior to use, the detector response must be checked by bringing it close to a source of radiation and verifying that it is able to see a signal.

Experimental detectors may be used to detect emissions. The requirements applicable to these detectors are:

- They must be operated to detect RF emission sources at a level significantly lower than permitted by SLAC policy.
- The entire system must be demonstrated to work by detecting a source of leakage – this will additionally test the trigger-timing of the oscilloscope or the settings of the network analyzer as applicable.

The sensitivity for home-built loop-antennas can be estimated as by estimating the loop area in square cm. For example, for the detection of RF emission in a pulsed L-band source, the permissible radiation level that your eyes can be exposed to is 85 mW/ cm^2. With a 2 cm diameter loop (area = π cm^2), the signal level entering the RF detector diode would be 0.26 watt (or 24 dBm!). Coupling the antenna to a detector diode set to respond with signal levels of 0 dBm, flange leakage can be reliably detected at emission levels far less than the permissible whole-body or eye exposure limits.

<u>Non-Vacuum Flange Assembly:</u>

- Verify that there is an operations lock on the power source when working on a system connected (or which could be connected) to an operable klystron.
- Apply LOTO lock and tag if the above conditions are met.
- If joint is to be disassembled and is labeled with a safety tag, contact Project Manager for removal of tag prior to disassembly.
- Examine both flanges for damage or defects.
- Assemble flange joint using appropriate RF gasket.
- Align flange using alignment pins (as applicable). Note: Rectangular X-band flanges do not use alignment pins.
- Bolt flange together. Apply correct torque on bolts.
- Verify bolt tightness.
- Remove personal LOTO lock and tag
- Apply safety tag (if applicable)
- Pressurize system (if applicable) and check for gas leaks
- Coordinate RF testing with Project Manager
- Turn on RF source to appropriate level. For klystron output, use lowest stable running conditions for klystron. RF drive systems may be set to nominal operation power levels.
- Check flanges for RF leakage. When using high-sensitivity detectors, establish a baseline radiation level for a well assembled flange and identify flange pairs that exceed RF emission expectations.
- Turn RF source to highest practical level (consistent with readiness of RF program and load)
- Repeat RF measurements
- If any joint has excessive emission which cannot be corrected, measurements must be repeated using a calibrated RF leakage detector.

<u>Vacuum Flange Assembly</u>

RF systems which achieve vacuum-tight joints using crushed metal gaskets are considered to be RF tight joints for the purpose of maintaining personnel safety.

Vacuum systems which depend on elastimetric seals, grease, or o-rings for the vacuum integrity must be checked using the protocols developed for non-vacuum systems.