An EM Radiation Safety Controller

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ABSTRACT

A safety control system has been developed for use in high power RF/microwave radiation exposure facilities. The system features Fail-Safe RF detectors, visible "RF ON" indicators, door-status sensors and digital logic to maintain safe opera conditions in spite of human errors or unsafe equipment malfunctions.

INTRODUCTION

The need for a personnel safety-monitoring/interlock-controlling device exists due to the increasing use of high-power microwave/RF generating equipment used in EM radiation testing, calibration, and biological effects facilities. In these facilities this equipment can cause acute injuries to operating personnel due to accidental exposure to intense electromagnetic fields. Many presently-manufactured high-power RF/microwave generators possess inadequate "power on" indicators, interlock circuits, and other safety features which are fail-safe. This can create unsafe situations in which operating personnel can be exposed to high field strengths after supposedly "turning off" the equipment or tripping an interlock, while in reality, no power shutdown has occurred due to faulty relays, switches, etc. Another common cause for accidental exposure is human error in which a person enters an EM radiation area, forgetting to turn off a high-power source. Because inadequate visible indicators or exposure area personnel sensor circuits are in the system, the forgetful person would be exposed unnecessarily to electromagnetic radiation. Similarly, one person could shut down an RF microwave source and enter the "exposure zone" while a second person could reactivate the source and expose the second person not knowing that someone was in the exposure zone. The exposed person would not be warned of the situation due to a lack of visible and audible indicators in the high-field-strength zone, and might only realize he was being exposed by sensing warmth due to RF heating effects. All of the above incidents have occurred in operational situations.

A safety controller has been developed to provide fail-safe protection for operators and users of high-power microwave and RF generators. The system uses multiple fail-safe RF detectors to monitor the presence of transmitted or radiated power, together with "door status" sensors which monitor access points to the hazardous exposure area. Digital logic is then used to determine potentially hazardous situations in which a person could be in a location where high field strengths exist. Once such a situation is detected, the controller activates visible and audible alarms, and the high-power source is turned off, via redundant relays.

CONTROLLER SYSTEM DESCRIPTION

A block diagram of the controller integrated into a typical microwave exposure facility is shown in Figure 1. One set of controller inputs consists of two contact closures which can be activated by exposure-area "door status sensors" such as mechanical switches, light-beam/photocell sensors, or a pressure-sensitive mat on the floor of the exposure area passageway. The sensors are fed into latching circuits, so that once tripped, they remain so until reset with a push button on the safety controller panel. The second set of inputs are two RF sensors consisting of commercial diode detectors in coaxial mounts. These detectors may be used to sense transmitted power when connected to the generator's waveguide or coaxial output port via a suitable directional coupler or signal-sampler. They may also be connected to a small antenna, placed in the exposure zone, to monitor radiated fields. The detectors are operated in a biased mode, and are part of a "balanced bridge" circuit which continually monitors the diode detector to ensure that it is both connected to the controller system, and is neither open nor short-circuited due to RF overloading or static electricity damage. This bridge uses a second identical diode detector mount, not connected to the RF source, as the reference element of the bridge circuit (Figure 2). An unbalanced condition of the bridge exists if the RF detector receives RF or microwave energy, or if it is open or short-circuited. Thus, a failure of the detector is a safefailure, causing the safety controller to receive a false "RF-on" signal. With a 1N23 diode in a standard coaxial mount, approximately 0.1 mW is sufficient to turn the detection circuitry to the "ON" state. At microwave frequencies, a half-wave dipole connected to the above crystal detector will activate the detection circuitry when irradiated by fields below one mW/cm^2.

The controller utilizes digital CMOS logic circuitry for increased noise immunity. Basically, the controller uses a key operated "master switch" which the user places in the "on" or "off" position. This switch activates the appropriate logic and relays which can activate a high-power RF generator. The key is removable only in the RF off state, so that the user may enter the exposure zone and automatically prevent another person from

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reactivating the RF generator. Detector outputs are monitored to establish whether or not RF power is actually being generated. Any discrepancy between the master switch condition and the actual RF detector output status results in a system "error condition" which sounds an audio alarm and provides a relay contact closure which can be used to shutdown the RF generator by removing its AC power input. The system's audio alarm and shutdown circuits are delayed by a user-variable control (1-60 seconds) to allow time to correct the error-causing condition before these emergency operations occur. A second function of the system logic is to monitor the exposure zone door status sensors and turn off the RF generator via interlocks, whenever the sensors are activated (as when a person enters the exposure area) during the generation of RF power. The system is illustrated in Figure 3 and its performance is described in Table I. Different component-failure situations are analyzed in Table II. Even if the RF generator in use has no provisions for remote shut-down via interlocks, the safety controller can establish a safer operating situation by sounding alarms and activating indicator lights if the generator is not turned off when a person enters the exposure zone with the RF on, or if the person turns off the master switch without simultaneously shutting off RF power. Under these conditions the system serves as a silent safety monitor, reminding a user to shutdown the generator at appropriate times.

Operation of the controller's outputs and its indicators involves the activation of red or green lights when RF power is, or is not being generated. These indicator lights are both on the safety controller itself and in remotely-mountable housings for installation in strategic places around the exposure zone. A second set of outputs, which were previously mentioned, are two relay-contact closures which can control both the RF generator interlock and a high-power coaxial switch. This coaxial switch can divert RF output power from the exposure-zone antenna to a suitable load termination. Alternatively, the coaxial switch can divert RF power from the input of a high-power amplifier to a passive termination. All system inputs are electrically isolated from the system logic by optically-isolated switches (with their own separate DC power supply). Similarly, optically-isolated output relays which drive electro-mechanical relays, provide the logic circuitry with a high degree of noise immunity, and prevent false operation even in areas with high levels of conducted and radiated interference signals. The system is housed in a rack-mounted enclosure and operates on 110 VAC 60 Hz power. System hardware is pictured in Figure 4. The equipment has been operated with several high power RF/microwave generators and has proven reliable, providing fail-safe protection of personnel who operate a high power microwave radiation calibration and test facility. A commercially-available version of the system has been produced by Eltek Corporation, Gaithersburg, Maryland, and is in use in a laboratory exposure chamber in conjuction with several high-power microwave generators.

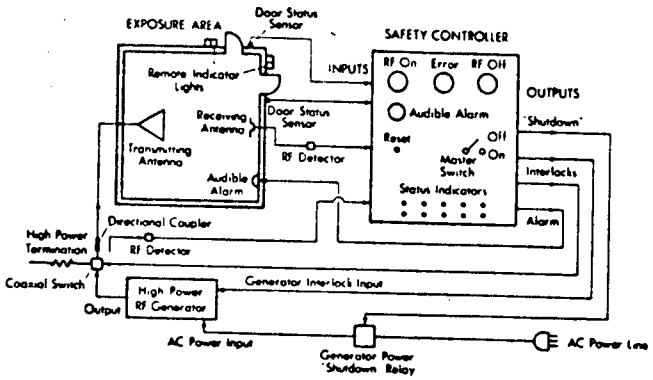

Figure 1 Safety Controller Installation

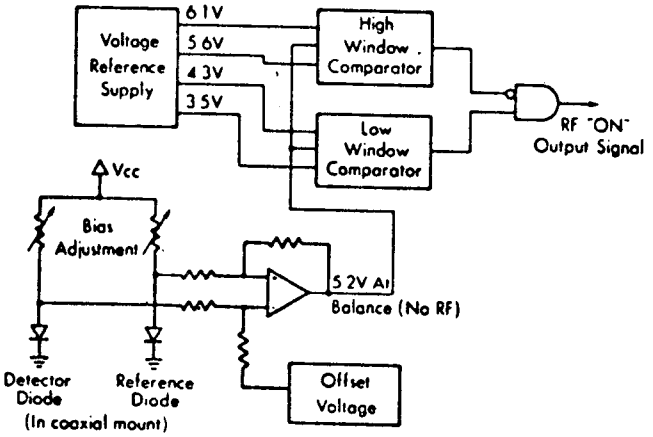

Figure 2 , RF Detector "Bridge"

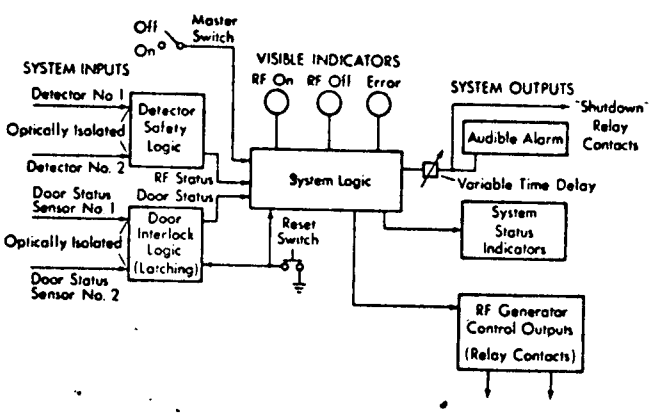

Figure 3 Controller System Block Diagram

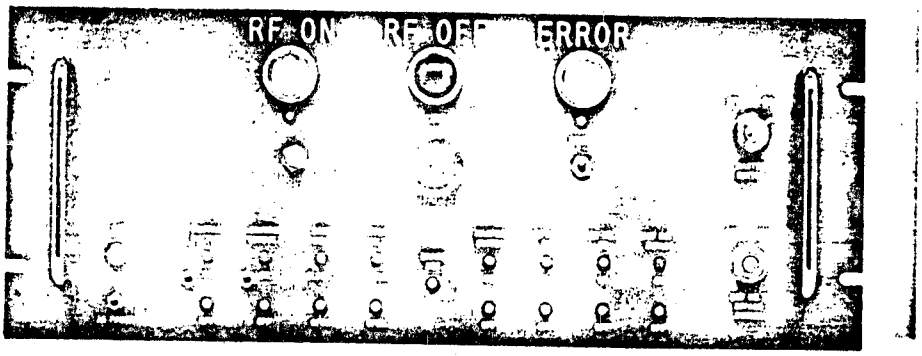

Figure 4

Safety Controller Unit

TABLE I. NORMAL SYSTEM PERFORMANCE

INPUTS			OUTPUTS	INDICATORS			
MASTER SWITCH	DOOR STATUS SENSORS*	RF DETECTORS	TWO RELAY CONTACT CLOSURES TO RF GENERATOR	RF ON LIGHTS	RF OFF LIGHTS	ERROR LIGHT* AND AUDIBLE ALARM	COMMENTS
ON	ON (DOORS CLOSED)	DETECTORS 1 AND 2 "ON"	CLOSED. (GENERATOR ENABLED)	ON	OFF	OFF	NORMAL RF ON CONDITION
OFF	ON OR OFF (DOORS OPEN OR CLOSED)	DETECTORS 1 AND 2 "OFF"	OPEN. (GENERATOR DISABLED)	OFF	ON	OFF	NORMAL RF OFF CONDITION
ON	OFF (DOORS OPEN)	DETECTOR 1 OR 2 ON	OPEN. (GENERATOR DISABLED)	ON	OFF	ON*	ERROR CONDITION: DOOR OPEN WHEN MASTER SWITCH ON
		DETECTOR 1 AND 2 OFF		OFF	ON	ON*	
OFF	ON OR OFF (DOORS OPEN OR CLOSED)	DETECTORS 1 OR 2 ON	OPEN. (GENERATOR DISABLED)	ON	OFF	ON*	ERROR CONDITION: RF DETECTED WHILE RF GENERATOR DISABLED
ON	ON (DOORS CLOSED)	DETECTORS 1 OR 2 OFF (NOT BOTH)	CLOSED. (GENERATOR ENABLED)	ON	OFF	ON*	ERROR CONDITION: RF GENERATOR ENABLED BUT NO RF DETECTED
		DETECTORS 1 AND 2 OFF		OFF	ON	ON*	

* REMOTE "RF ON" LIGHT ON DURING ERROR CONDITION

TABLE II. FAILURE ANALYSIS

FAILURE CONDITION	SYSTEM REACTION	STATUS
DIODE DETECTOR BURNOUT (OPEN OR SHORT)	"RF ON" CONDITION ESTABLISHED IN SAFETY CONTROLLER. "RF ON" INDICATOR LIGHTS ACTIVATED. ERROR INDICATORS AND ALARM ACTIVATED WHEN MASTER SWITCH IS TURNED OFF.	FAIL-SAFE
RF GENERATOR INTERLOCK FAILURE. GENERATOR ALWAYS ON	RF DETECTORS AND DOOR STATUS SENSORS MONITOR CONDITIONS. "RF ON" LIGHTS ACTIVATED. ERROR INDICATORS AND ALARM ACTIVATED WHEN MASTER SWITCH IS TURNED OFF	FAIL-SAFE
DOOR STATUS SENSOR FAILURE IN CLOSED CONDITION	"RF ON" LIGHTS ACTIVATED WHENEVER RF IS GENERATED	INDICATOR LIGHTS ALERT PERSONNEL NOT TO ENTER EXPOSURE AREA EVEN IF DOOR IS OPEN
DIRECTIONAL COUPLER OR ANTENNA FAILURE (RF NOT DETECTED WHEN RF IS GENERATED)	ERROR INDICATORS AND ALARM ACTIVATED WHEN MASTER SWITCH IS TURNED ON. INTERLOCKS SHUT OFF GENERATOR WHEN MASTER SWITCH IS TURNED OFF.	FAIL-SAFE