COMPUTER-CONTROLLED RADIATED SUSCEPTIBILITY SYSTEM

An automated radiated susceptibility system, designed to generate 20 V/m field strength over the frequency range of 10 kHz to 40 GHz is detailed. Information on the selection of equipment required to generate the field is provided. The operation of a computer program used for automated susceptibility tests is described and the general flow of the program and the sequence of operations controlled by the program are explained.

E. L. Bronaugh and D. Pawlowski, Electro-Metrics*, Amsterdam, NY and R. Sivaswamy, EMC Automation*, Austin, TX

THE HARDWARE DESIGN: INTRODUCTION

Automation of EMI testing started in the early 60's and most of it was aimed at the automation of emission test systems. This was due to the fact that susceptibility testing is more complicated, and the equipment available for susceptibility testing at that time was not designed for automation. Complete automation of susceptibility is still not available in most cases because the equipment under test (EUT) is not under the control of the testing system. It is difficult to design a system to have computer control for different types of EUTs.

Automation reduces the likelihood of measurement errors and lost data, remotely controls the test system, provides the necessary data correction, and enables repeatable results.

SYSTEM REQUIREMENTS

For any automated system it is necessary to provide remote control for all the instruments used in the system. IEEE 488 bus interface (GPIB) is used for remote control of most of the instruments in the system. The only instruments that do not have direct GPIB control are some power amplifiers. These amplifiers use a special interface unit which allows communication between the amplifiers and the GPIB. RF path switching is also controlled via the special interface unit.

Radiated susceptibility testing is done by generating a known field strength over the required frequency range and by looking for the proper operation of the EUT when it is subjected to this field. If the EUT is found to be susceptible, then the field strength is changed to find the point of susceptibility.

The system consists of two sections for generating and maintaining the field. They are the transmitting section, which is used to generate the required field, and the receiving section, which is used for measuring and calibrating the field. The transmitting section consists mainly of signal generators, power amplifiers, power meters, and transmitting antennas. The receiving section uses two types of field calibration. One method uses EMI receivers and EMI receiving antennas, and the other method uses broadband isotropic probes with fiber optic links for measuring and calibrating the field. Either method can be used to do the test. The method using broadband isotropic probes is a real-time monitoring system, but is subject to errors caused by probe placement and local field perturbations.

SYSTEM CONCEPT

All calculations for generating the field assume far field conditions. The design is aimed at generating the required field at 1 meter distance from the transmitting antenna. To keep the number of instruments in the system to a minimum, broadband amplifiers, broadband antennas, and signal generators operating over wide frequency ranges are used. The system uses three signal generators, two to generate the required frequency in the range of 10 kHz to 40 GHz, and the third to provide the modulation. Nine amplifiers are used to cover the full frequency range. The amplifiers drive six antennas working over different frequency ranges to generate the field. To measure and calibrate the field, the receiving system uses two EMI receivers and six receiving antennas for one method, and six field sensors with fiber optic link for the other method.

Standard EMI antennas are used for both the transmitting and the receiving sections. The transmitting antenna gain data is obtained from the antenna manufacturer. Knowing the antenna gain, the power required at the input of the antenna to generate the field can be calculated. Taking into account the losses in the system and assuming 0 dBm of maximum signal generator output, the amplifier gain and the amplifier power output required are determined. From the calculated values of power required, the amplifiers are chosen, based on the most suitable combination of frequency, power, and cost. Other factors considered for the design are remote control, amplifier protection, and the type of amplifier.

For the receiving section, the design for the method using EMI receivers and antennas is simple because it uses standard receiving antennas and GPIB controlled receivers. Care must be taken to ensure that the receiving antennas and the EMI receiver can withstand the field being generated. The method involving isotropic probes uses a specially designed fiber optic interface. The interface provides data, range, and battery status information to the computer.

*See advertisement on pages 75 and 77.

SYSTEM DESIGN

The frequency range of 10 kHz to 40 GHz can be divided into smaller ranges, depending on the antennas used in the system.

An E-Field parallel element antenna is used in the range of 10 kHz to 30 MHz. The field generated by the E-Field antenna is directly proportional to the voltage fed to the antenna at its terminal. The field strength versus input voltage plot is normally provided by the antenna manufacturer.

For a 20 V/m system, the input voltage required to generate the field is calculated from the plot, and the power required to generate this voltage is determined. The parallel element antenna impedance is normally not equal to 50 ohms over its operating range, so an adequate power margin is provided to compensate for the change of load impedance.

For the frequency range greater than 30 MHz, the amplifier power required to generate the field is calculated from the field equation:

$$E^2 = 30(Pt)(Gt)$$

where:

E is the field strength in V/m,

Pt is power to the antenna in watts, and

Gt is the numeric antenna gain.

The equation can be rewritten as:

$$20 \log(E) = 10 \log(30) + 10 \log(Pt) + 10 \log(Gt)$$

The antenna gain in dB is 10 log(Gt) and is normally provided by the antenna manufacturer. The equation is solved for the amplifier power required in dB(W) for a 20 V/m system.

The following are the antennas used in the system for the frequency range of 30 MHz to 40 GHz.

- High power biconical from 30 MHz to 200 MHz
- Double ridged guide antenna from 200 MHz to 1 GHz
- Double ridged guide antenna from 1 GHz to 18 GHz
- Standard gain horn antenna from 18 GHz to 26.5 GHz
- Standard gain horn antenna from 26.5 GHz to 40 GHz

When the power requirements are calculated, antenna impedance mismatch, path loss, cable loss, and RF switching loss are considered. Amplifier selection is thus based on the following:

- Minimum theoretical power required.
- Total system losses, e.g., cable, mismatch, etc.
- Amplifier cost, keeping the number of amplifiers to the minimum for the required frequency range and with the required power.
- Availability of broadband amplifiers with the required output power.

The block diagram of the system is shown in Figure 1 and Table 1 gives the typical power output of the amplifiers used in the system.

FIELD CALIBRATION

As discussed earlier, two methods of field calibration are provided in the system.

The method using the EMI meter reads the field strength in terms of dB(μV/m) and converts it to V/m to level the field at 20 V/m. Forward and reflected power are stored at the required field levels at frequencies of interest and generator output is adjusted for the same net forward power when the test is run with the EUT. The system has the facility to reduce the generator level in case the EUT is found to be susceptible. The field strength is calculated from net forward power at the point of susceptibility.

The method using the isotropic probe provides real time monitoring of the system under test. The field leveling is done by placing the isotropic probes (system has the capability to accept up to 3 probes) near the EUT, and the field is set to the required 20 V/m by reading the probe output and adjusting the generator output for the required level of probe output.

For many isotropic probes, the output reads in terms of power density in mW/cm^2. This output is converted to field strength in terms of V/m by using the equation

$$P = E^2/R$$

where:

P is in W/m^2,

E is in V/m,

R is in ohms. (377 ohms)

THE CONTROLLING SOFTWARE: INTRODUCTION

Software design requirements are an integral part of creating an automated susceptibility test system. Since it is difficult to completely automate a susceptibility test system, this program is written to provide the necessary system setup information to the operator. The software uses interactive dialogue and allows the operator to monitor test data, modify test parameters, or change the sequence of operation. The program continuously displays all vital test parameters, such as amplifier status and field level. The software is written in basic and is fully menu driven.

Range	Antenna	RF Power
10 kHz - 30 MHz	PEA - 25	400 W
30 MHz - 200 MHz	BIA - 30H	400 W
200 MHz - 1 GHz	RGA - 30	50 W
1 GHz - 18GHz	RGA - 60	20 W
18 GHz - 26 GHz	SH - 60-1	1 W
26 GHz - 40 GHz	SH - 60-2	1 W

POWER LEVELS BASED ON:

- Theoretical Power
- Total System Losses
- Amplifier Cost
- Availability of Amplifiers

1 dB loss at 400W is >82 W!
Control of loss is very important

Table 1. Frequency Ranges, Antenna, and RF Power.

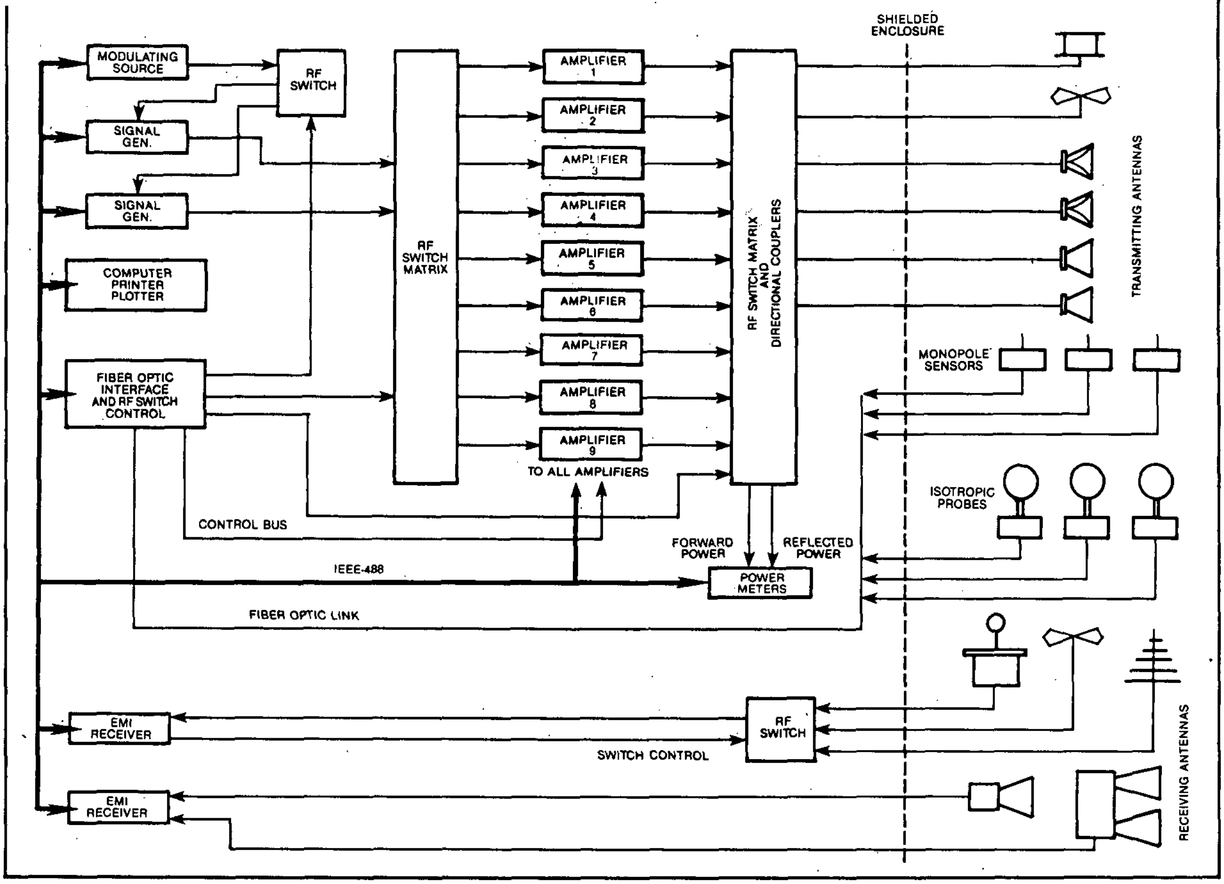

Figure 1. Block Diagram of System.

PROGRAM ORGANIZATION

The program consists of the following major sections:

- System initialization
- Test parameter selection
- Test setup details
- System control and data acquisition
- Test results and display functions
- Data storage and data output

The general flow of the program is shown in Figure 2. At each stage of the program, the operator is provided with all of the necessary system information and system controls.

SYSTEM INITIALIZATION

The program starts with a self-test routine to ensure that all the necessary instruments on the GPIB are powered and it runs a small self-test program on some of the instruments used in the system. If it finds any problem during self-test, the operator is prompted with an error message. After the system passes a self-test, the program starts a system initialization routine, setting the system to the following conditions:

- Sets all the signal generators in the system to the low end of the frequency range
- Sets all signal generators RF to Off
- Sets all amplifiers to power On, RF Off, and runs a status check on all amplifiers to ensure proper initiation
- Terminates all transmitting antenna inputs to dummy load
- Initializes the EMI receivers
- Initializes the power meters and runs a zero calibration on the power meters
- Initializes the isotropic probes and their interfaces and runs a status check

TEST PARAMETER SELECTIONS

Once the system is initialized and found to be normal, the program allows the operator to enter the test parameters. Depending on the type of receiving system, the operator can select the required test method (Figure 3).

Once the test method is selected, the operator can create a new set of parameters or run a test with preset stored test parameters (the program can store up to 16 sets of test parameters under different test names).

If a preset test is selected, the system provides all the selected parameters of the test, allowing the operator to make any necessary changes by using the soft keys. Once the necessary test parameters are set, the operator can proceed to the test by selecting the soft key "GO ON". If a new set of test parameters is created, the operator is given the option to store the test under a new name. Figure 4 gives a typical test parameter display.

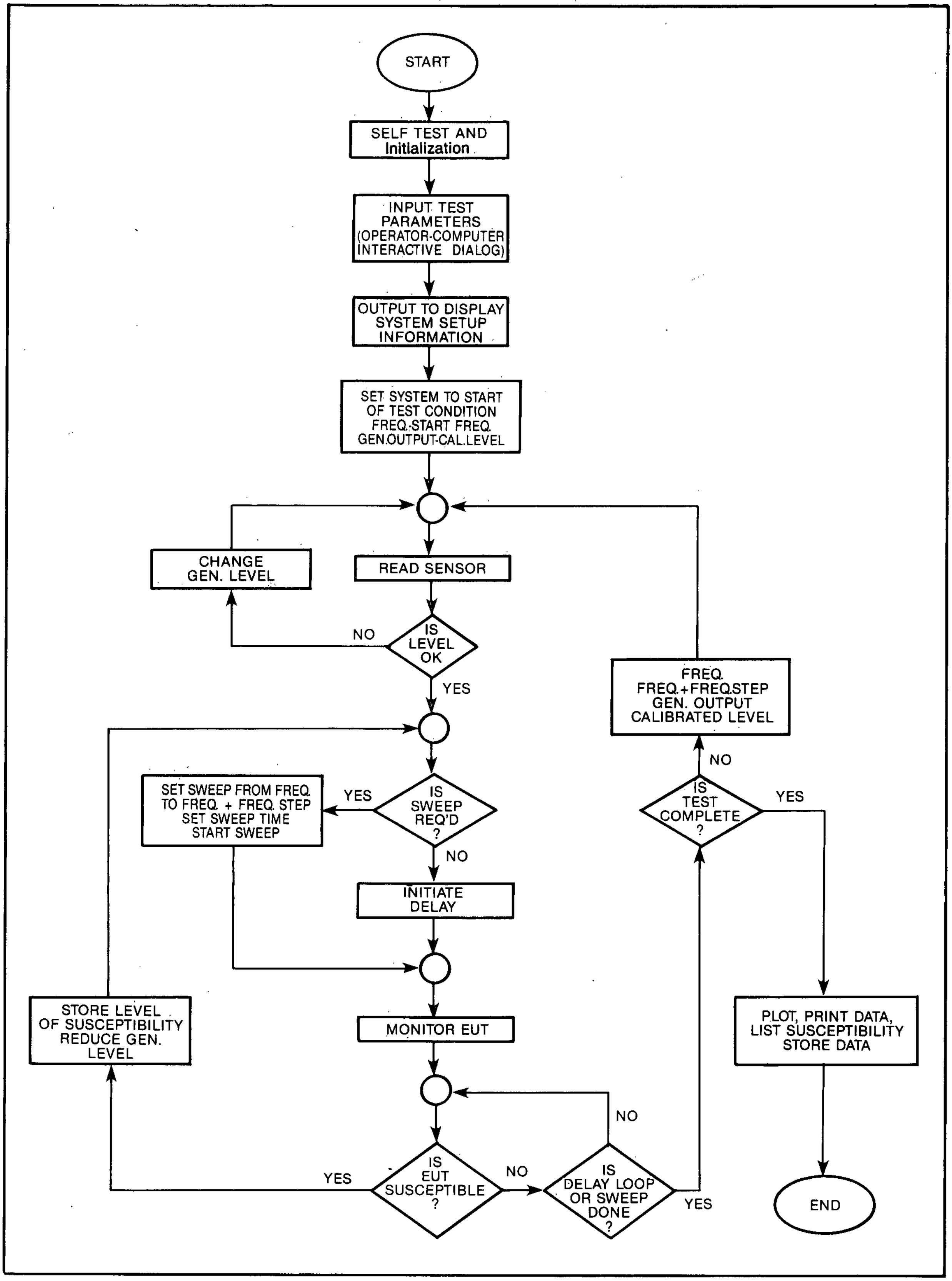

Figure 2. General Control Program Flow.

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THESE ARE THE AVAILABLE METHODS OF TESTING FOR RS03.

1) METHOD 1 -- A RECEIVING ANTENNA IS PLACED AT A ONE
                METER DISTANCE FROM THE TRANSMITTING
                ANTENNA IN ORDER TO SET THE DESIRED FIELD.
                THE REQUIRED POWER LEVELS ARE MEASURED
                AND STORED AND THE RECEIVING ANTENNA IS
                REPLACED BY THE 'EUT' FOR THE TEST.
                THIS METHOD IS AVAILABLE UP TO 40 GHz.
                NOTE: MUST INCLUDE AT LEAST 40 dB OF
                      EXTERNAL ATTENUATION TO PROTECT
                      RECEIVERS UP TO 18 GHz.

2) METHOD 2 -- THIS METHOD USES THE MONOPOLE ANTENNA
                FROM 14 kHz TO 200 MHz.

3) METHOD 3 -- THIS METHOD USES AN ISOTROPIC FIELD
                SENSOR TO MONITOR THE GENERATED FIELD.
                THIS METHOD ONLY AVAILABLE FROM 30 MHz
                TO 40 GHz.

ENTER THE DESIRED METHOD OF TESTING ?  ( 1, 2 OR 3 )
```

Figure 3. Test Method Selection Screen.

```
THESE ARE THE SELECTED PARAMETERS.  TO ENTER OR CHANGE VALUES
USE THE SPECIAL FUNCTION KEYS.  TO CHANGE KEY LABELS USE SFK
#8. TO GO ON TO THE TEST USE SFK #9.

FREQUENCY RANGE: 1 GHz TO 40 GHz      FIELD INTENSITY: 10 V/m

FREQUENCY STEP SIZE:  5 GHz           TIME DELAY: 25 SECS

TEST ITEM:                            MODEL NO.:

TEST MODE:                            DATE:

TEST NO.:                             SENSOR LOC.:

REPORT NO.:                           SENSOR POL.:

SERIAL NO.:                           FEET RF CABLE:

PRESET ATTEN.: 0 dB                  EXT. ATTEN.: 40 dB

-------------------------------------------------------------
I START FREQ I STOP FREQ I STEP SIZE I TEST ITEM I TEST MODE I
-------------------------------------------------------------
I TEST NO     I REPORT NO I SERIAL NO I LABEL CHGE I GO ON    I
-------------------------------------------------------------
```

Figure 4. Sample Preset Test.

```
PLACE THE 'EUT' ONE METER FROM THE SH-50-1 ANTENNA.
MOVE THE ISOTROPIC PROBE NEAR THE 'EUT'.

-------------------------------------------------------------
I          I          I          I EXIT TEST  I STOP RUN  I
-------------------------------------------------------------
I AMP OFF  I          I          I            I           I
-------------------------------------------------------------
```

Figure 5. Example of Test Setup Instructions

TEST SETUP INFORMATION

Once the test parameters are accepted, the program provides the operator with the information necessary to set up the test. For example, if the first method is chosen, the program will indicate to the operator which transmitting and receiving antennas are to be used for the field level calibration. The test setup information is provided to the operator whenever a change in the setup is required. Figure 5 gives a typical test setup indication.

SYSTEM CONTROL AND DATA ACQUISITION

System control and data acquisition form the main section of the program and is where the data acquisition and field generation are controlled. The sequence of the program is as follows:

- Depending on the frequency range of the test, the amplifiers and antenna RF path is set by the program.
- The generator is set to its initial level, which is stored in the program, based on the results obtained from system calibrations.

The field level is measured using the selected receiving system and the generator output is adjusted so the required field will be within the set tolerance.

The field calibration is done according to the following methods, depending on the type of sensor used. For EMI receivers, the calibration is done at discrete frequencies derived from test data on start frequency, stop frequency, and frequency step size. Then the receiving antenna is replaced by the EUT and tested for susceptibility by setting the generator to the calibrated level. The test can be run by setting the field at the discrete frequencies at which it is calibrated or by sweeping between the calibrated frequencies.

With the isotropic sensors, the test is run similarly to the method for the EMI receivers, except that the test is run in real time, avoiding a separate run for calibration. When the generator is set to sweep between the set frequency points, the isotropic probe can be set to monitor the field level to keep it within set threshold levels.

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*************  HUGHES  ( 18 - 26.5 GHz )  *************

 SUMMERY FAULT OFF                      HELIX FAULT OFF
 THERMAL FAULT OFF                      LINE VOLTAGE NORMAL
 OPERATE                                POWER ON

                                      -------------------------
*** MONITOR EUT ***                   I TIME DELAY : 25 SECS I
                                      -------------------------
                                           I  20 SECS  I
                                           -------------

FREQUENCY: 20 GHz           FIELD LEVEL : 10 V/m

-----------------------------------------------------------------
I          I          I          I  EXIT TEST  I  STOP RUN  I
-----------------------------------------------------------------
I AMP OFF  I          I          I             I            I
-----------------------------------------------------------------
```

Figure 6. Example of Test Monitor Screen.

FREQUENCY	OUTPUT LEVEL	REQ. LEV	THRESH. LEV	FAILURE
3.000 GHz	5.07 dBm	10 V/m	9.50 V/m	·······
5.000 GHz	6.24 dBm	10 V/m	9.00 V/m	·······
8.000 GHz	6.56 dBm	10 V/m	8.50 V/m	·······

* -- INDICATES THAT THE REQUIRED FIELD COULD NOT BE SET.

●●●●●● -- INDICATES A FAILURE AT THAT FREQUENCY.

······ -- INDICATES SUSCEPTIBILITY LEVEL OF FAILURE.

Figure 7. Example of Test Data List.

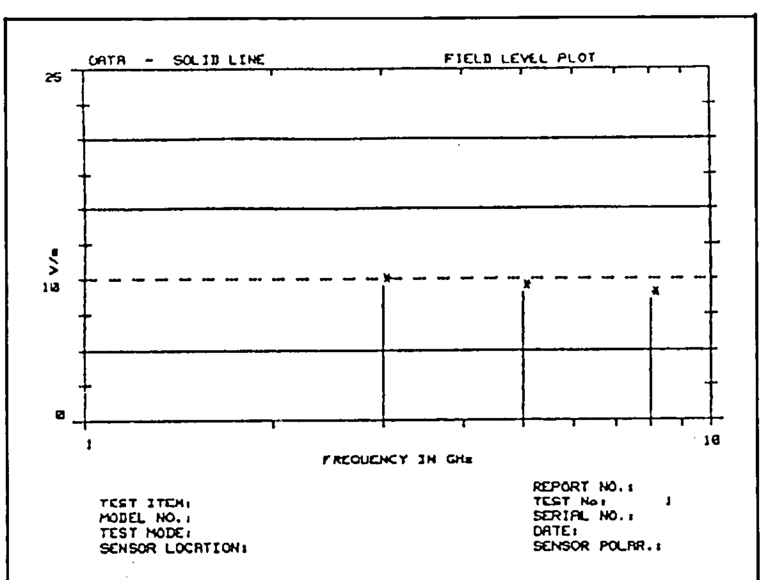

Figure 8. Example of Graphical Display Data.

During the test, the operator is prompted to monitor the EUT for susceptibility (Figure 6). The sweep and delay for discrete frequency steps can be set to provide adequate monitoring time. The lapsed time at each frequency is shown below the set delay time.

If the EUT is found to be susceptible, the test can be stopped and the generator level can be changed in 0.5 dB steps to find the level of susceptibility. The frequency and the level of susceptibility can be stored and the test continued.

The level of susceptibility is actually measured using the isotropic probe, if the probes are used for field measuring. In case of EMI receivers, the field level is calculated from net forward power information read using power meters. (The E-field is proportional to the square-root of the net forward power.)

At the end of the test, the program has the facility to list the frequencies and the levels of susceptibility. The test parameters and test results can also be stored.

The software with the associated hardware provides the necessary system and operator protection. Following are the system and operator protection features provided by the system.

Amplifier Monitoring and Protection. The amplifiers in use are continuously monitored during the test by reading their status information, which is continuously displayed. In case of a defect, the operator is immediately prompted by display of an error message and an audible alarm. (The display in Figure 6 is reconfigured.) The program also initiates a time delay for the operator to take action. The program redefines the soft keys to provide the necessary amplifier control functions for the operator. If the operator does not take any corrective action within the set time delay, the program automatically initiates the necessary commands to protect the amplifier.

Interlock Monitoring and Control. The system provides interlock switch control and monitoring. One switch is directly under the control of the operator. This switch is used to disable power to the amplifiers in case of an emergency. The computer has control to set the switch to the off state only. The other switch is used for the shielded room. The computer continuously monitors the status of this switch and if the shielded room is opened during the test, the program immediately sets RF off for both the amplifier and the signal generator which are in operation. The RF path to the antennas is also disabled.

Field Level Threshold. A threshold level for maximum field can be set to protect the EUT. The program will not allow an increase in output if the threshold is reached at any time during the test. Different threshold levels can be set for different frequency ranges.

TEST RESULTS AND DATA STORAGE

Once the test is completed, the operator can print and/or plot the data, as shown in Figures 7 and 8. The test parameters and the test data can also be stored. The program also provides the facility to analyze stored data.

CONCLUSION

EMC testing requirements continue to increase in our society, creating a need for more efficient and reliable test sytems, which can be achieved by automation. With continuing developments in instrumentation automation, susceptibility test systems will become less dependent on human intervention, leading to a near ideal automated susceptibility test system.

An automatic susceptibility test system provides many advantages over manually controlled systems. The performance of an automatic susceptibility test system mainly depends on the system software that controls the system operations. With the increase in requirements of automated systems, the software for such systems is becoming more user friendly and much more powerful. ■

NOTE

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