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PERFORMANCE MEASUREMENT AND TEST TECHNIQUES FOR MODERN AM BROADCAST TRANSMITTERS

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***Abstract* - "Performance Measurement and Test Techniques for Modern AM Broadcast Transmitters" will discuss the numerous tests required in evaluating the performance of a modern AM transmitter. In developing the latest in AM transmitters, Harris has generated a comprehensive list of performance, environmental, and ruggedness tests designed to fulfill the needs of a modern broadcaster. These needs include maximum audio performance in both mono and stereo, high overall efficiency for lower operating costs, reliability even under adverse environmental conditions, and protection against extreme ac line/output load variations. The latest attainable performance measurements, environmental testing requirements, and field condition simulation tests will be discussed.**

Introduction

In radio broadcasting, the 1980's have been a decade of transition from tube to fully solid state amplification. Whereas high power VHF solid state amplifiers are in the initial stages of development for widespread commercial use, medium wave (MW) broadcasting with a fully solid state transmitter is now the widely accepted standard.

With the development in the 1970's of solid state MW transmitters, new problems were encountered with them operating outside of the laboratory environment. The solid state transmitter tended to be more susceptible to voltage transients introduced via the incoming power line and high load VSWR of both short and long duration. Tests were developed in the laboratory to simulate these conditions in order to obtain maximum reliability as early in the transmitter design as possible. With the introduction of solid state transmitters, broadcasters were rewarded with audio performance that was literally unheard of in a tube transmitter. With the more recent development of digital amplitude modulation, audio performance is now obtaining goals typical of those realized in FM broadcasting. This decade also saw AM stereo as essential to the longevity of AM broadcast in many parts of the world. Even though a standard has yet to be declared in many countries, new transmitter performance requirements were dictated to achieve optimum acceptable stereo performance.

Laboratory Tests Of New Products

There are four major categories of tests that are performed during the evaluation of a new transmitter. Audio performance testing is used to verify all specified performance goals. Many improvements have occurred in both the performance specifications and measurement equipment. Non-audio performance testing includes overall efficiency measurement which is a major concern of many broadcasters faced with increasing operating costs. Environmental testing is used to evaluate the operation of the transmitter when subjected to the different climatic variations that are encountered throughout the world. Ruggedness testing is used to simulate variations in ac power and RF output impedances which tend to pose problems to solid state transmitters. These series of tests are performed throughout the development of the transmitter with final production units receiving only the performance testing and selected ruggedness tests that the design team feels are required to maintain high reliability.

Audio Performance Testing

Successful audio performance testing is one of the major goals in transmitter development. The accuracy of the results are important to the future of the product. Many of the tests performed have been in existence for quite some time and still are important to the modern AM transmitter. Recently, more tests have been developed and implemented in order to more closely characterize the transmitter's audio performance.

Test Equipment and Set-Up

All performance data shown was taken by the Audio Precision System 1. This and other recent audio generator/distortion analyzers, operate with menu driven screens on a standard personal computer or with a self contained microprocessor and external monitoring. These units will perform the complete set of audio tests with graphic print outs, in less than 5 minutes. This compares favorably with manual test equipment that would require over 30 minutes to perform the same evaluation. With such equipment, audio sweeps can be performed repetitively to allow instant feedback during transmitter adjustment or after internal component changes. Fig. 1 is a diagram of a test setup used to perform most of the audio performance measurements discussed.

Mono Audio Performance Tests

Audio Frequency Response - Frequency response in the latest AM transmitters will typically be specified to +-0.5dB from 20Hz to over 10kHz. Attaining the transmitter frequency response to within the latest specifications is not a major hurdle in development. Most transmitters will include a low pass filter to improve overshoot and reduce higher frequency modulation. This filter may be replaced by an National Radio Systems Committee (NRSC) standard as required in the U.S.

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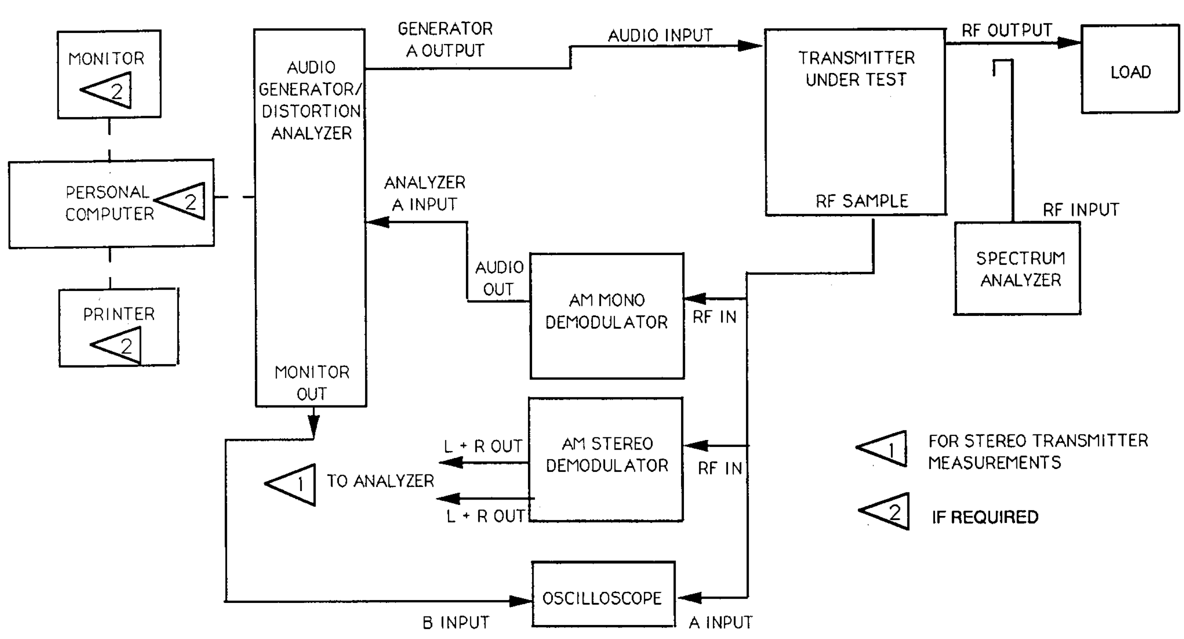


Fig. 1. Typical Test Equipment Connections for Audio Performance Measurements

Total Harmonic Distortion (THD) - Like response, THD is one of the basic barometers of a transmitters audio performance. In the last two decades, typical THD numbers have dropped from 3% to 0.3%. Fig. 2 is a typical THD and response versus frequency sweep of a digital AM transmitter at 95% modulation. During the transmitter development stage, the THD versus frequency sweep can be very useful in identifying distortion problems occurring at specific frequencies. Fig. 3 is a graph of THD versus modulation level of the same transmitter. This type of sweep is very effective in identifying a higher than normal THD that occurs at a specific modulation level.

SMPTE Intermodulation Distortion (IMD) - The SMPTE Intermodulation Distortion test signal became a valuable tool to characterize a transmitter's performance in addition to basic THD tests. Typical SMPTE IMD specifications range from 1% to 2%. Earlier model transmitters could do no better than 5% IMD. Typical 4:1 IMD now averages 0.2 to 0.8% at full output power and 95% modulation.

AM Signal To Noise (S/N) - In order to measure a modern transmitter's typical THD of 0.2%, the signal to noise must be -54dB or greater. Signal to noise ratios of -60 to -65dB are now commonly specified numbers, with -70dB to -75dB now attainable.

Positive Peak Modulation - 125% positive modulation is still the FCC maximum legal asymmetrical modulation. Many stations require the transmitter output power to be +20% over licenced power in order to overcome transmission system losses. With the requirement for 125% positive peak modulation at +20% rated power, the transmitter design now has the headroom built in for positive peak modulation of 150% and higher at the standard output power.

Carrier Shift - Modern AM transmitters will many times utilize power supply feedback to produce results that allow typically less than 0.5% carrier shift at all modulation levels.

Squarewave Tilt And Overshoot - Transmitters such as a digital AM unit, that do not utilize a modulator with filter inductance, can reproduce a 400Hz 80% modulated squarewave with less than 1% overshoot. Tilt at 40Hz can be less than 1%.

CCIF Intermodulation Test - The CCIF intermodulation signal is a more recent development in characterizing an AM transmitter's performance. Measurements of the 1kHz (F1-F2) intermodulation product of a 9kHz/10kHz test tone are typically from -45dB to -55dB. This has reduced the coloration of sound compared to the older transmitters.

Transient Intermodulation Distortion (TIM) - Known as Dynamic Intermodulation Distortion, this is probably one of the newest tests to be performed on broadcast products. THD, SMPTE, and CCIF IMD tests can result in near identical numbers for competing transmitters, and the use of the TIM test has revealed significant differences which can clearly distinguish the more accurate transmitter by its Transient Intermodulation Distortion. The measurement equipment to easily evaluate TIM is now becoming available for broadcast use. TIM readings range from 0.2% on a digital AM transmitter to up to 2% on other transmitters of different modulation types. This is basically due to the slew rate of the modulator stage.

Out of Band Emissions - With the emphasis on improving AM by reducing the adjacent channel interference, emissions outside of the occupied bandwidth is an important issue for both manufacturer and broadcaster. With the adoption of the NRSC standard in the U.S., the limits for undesired spectral products are lowered in order to reduce interference. Fortunately, as competition requires that audio performance of the modern transmitter improve, this tends to allow the transmitter to more easily comply with the out of band requirements by default. This is true at least in terms of products caused by harmonic and intermodulation distortion. The manufacturer must still ensure that other spectral products are attenuated within legal limits. Fig. 4 compares the occupied bandwidth of a new Digital AM trans-

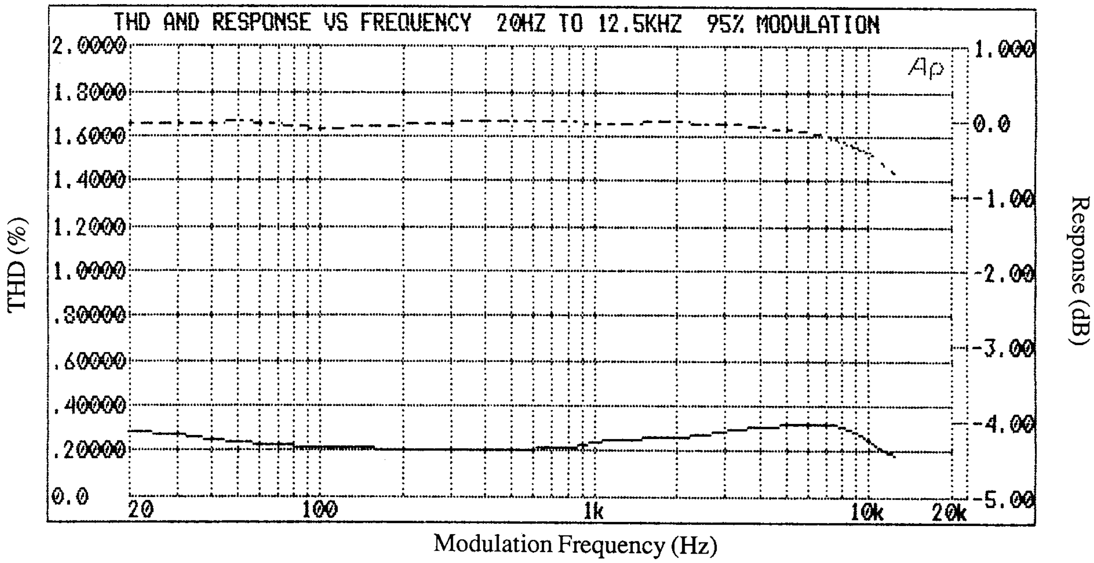


Fig. 2. THD and Response versus Frequency. Referencε 1kHz @95%
Response - Dotted Trace
THD - Solid Trace

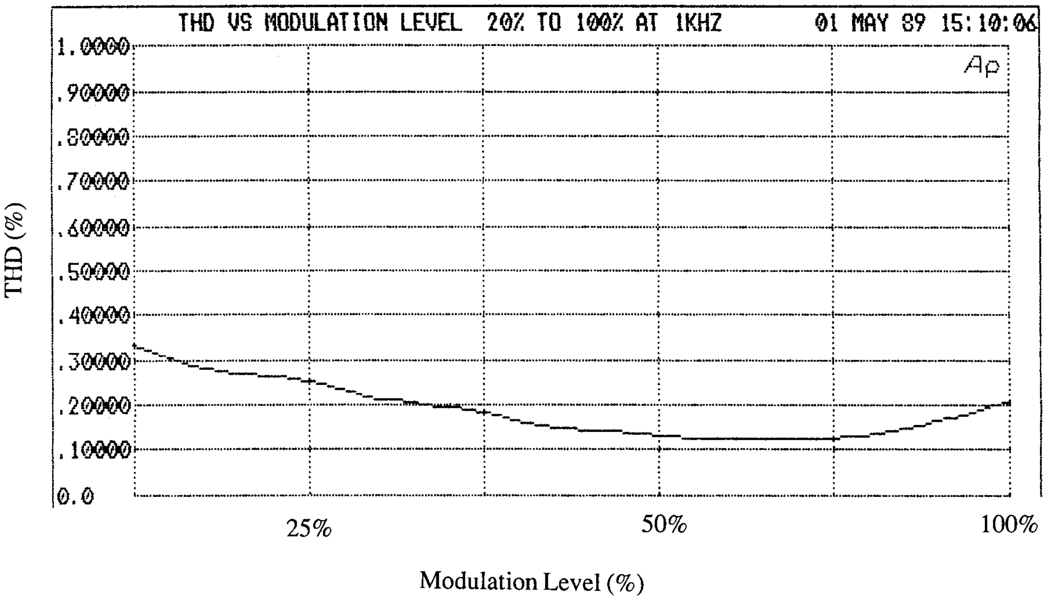
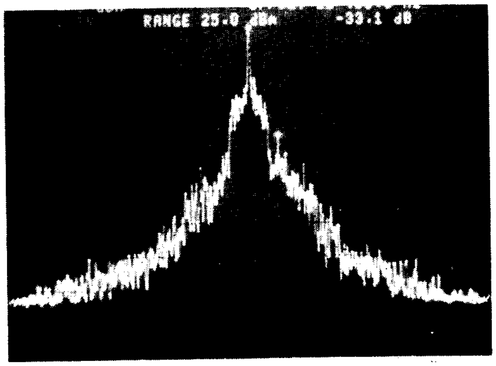
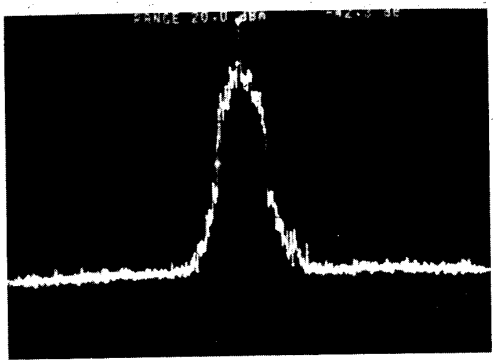


Fig. 3. THD versus Modulation Level. Sweep from 20% to 100% Modulation at 1000 Hz



Tube Type AM Transmitter



Digital AM Transmitter

Fig. 4. Comparison of Occupied Bandwidth of Tube Type versus Digital AM Transmitter.
Test Setup is as specified by NRSC Guidelines [4]
Span - 20 kHz/Div
Resolution - 300 Hz
Center Frequency - 1530 kHz

mitter to that of an early model tube transmitter. Both photos were taken at the same site, modulated from the same audio source utilizing the current NRSC standard.

Stereo Audio Performance Testing

With the advent of AM stereo, a new set of measurements for AM transmitter performance became as important to a stereo broadcaster as THD and response. The following are limiting factors in a stereo transmitter operating with the C-QUAM AM stereo system and tests are now performed to obtain the maximum stereo performance.

Incidental Quadrature Modulation (IQM) - IQM has always existed in AM transmitters but measuring it was never an issue until C-QUAM stereo. IQM is one of the limiting factors in attaining acceptable AM stereo performance, more specifically stereo separation and distortion. IQM in the latest transmitters has now been improved to specifications of -35dB or greater. See Fig. 5 for a sweep of IQM versus frequency.

L-R Response - The bandwidth of the entire transmitter RF drive chain is a consideration in transmitter design in order to allow minimum attenuation of the L-R information at the higher modulation frequencies. The L-R response referenced to 95% L-R modulation of a stereo exciter/transmitter at 1kHz will normally remain within +-1.0 dB up to 10kHz. The station antenna system typically becomes the limiting factor in stereo L-R response.

Stereo Summary - In modern AM transmitters, with IQM approaching -50dB and the RF chain optimized to be almost transparent to the L-R information, stereo performance through a new AM transmitter is now mostly limited by the exciter/monitor performance and antenna system characteristics.

Other Performance Measurements

Overall Efficiency/ PA Efficiency - As the cost of electricity continues to increase, the cost of operation becomes a very important issue when replacement of the old transmitter becomes necessary. Overall efficiency has become one of the key transmitter performance factors when considering a new transmitter design. Overall efficiencies of tube type, high level modulation transmitters would typically be in the range of 40 to 60%. Solid state transmitters utilizing modulation schemes such as Pulse Duration Modulation (PDM), can now achieve overall efficiencies of up to 75%. More recent developments such as digital amplitude modulation, can achieve overall efficiencies up to 86% due to elimination of the modulator stage. Fig. 6 diagrams the test setup for accurate measurement of overall efficiency.

Conducted Harmonics And Spurious - Even with the use of high efficiency class D RF amplifier designs, attenuation of harmonic and spurious emissions to at least minimum FCC standards has not been a major design problem in AM transmitters.

Environmental Testing

Purpose

All of the measurement topics discussed up to this point are concerned with how a transmitter will satisfy the customer in terms of audio performance, operating efficiency and operation within legally defined limits. The modern AM transmitter must be able maintain all its design specifications, operate reliably and within all component specifications while subjected to environmental conditions expected throughout the world.

Temperature Testing - The design of any transmitter should allow it to operate within a range of ambient temperatures while still meeting the published specifications and maintaining stress of all components below their maximum ratings. The commonly accepted operating temperature range for AM broadcast equipment is 0 to 50 degrees C. In many cases, somewhat wider ranges are specified for operation in unusual conditions.

Humidity Testing - Associated with the temperature testing is humidity testing. The typical humidity range specified for an AM transmitter is 0 to 95%, non-condensing. The function of the humidity tests is to locate areas in the transmitter in which high humidity may produce a potential for component failure. Both temperature and humidity are tested in conjunction in an environmental test chamber.

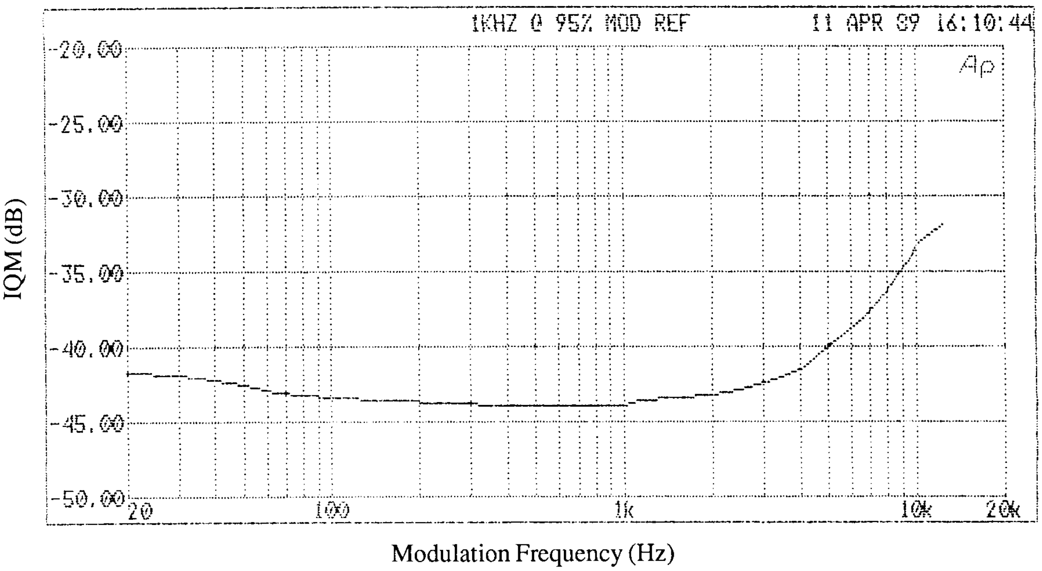


Fig. 5. Incidental Quadrature Modulation versus Frequency
Reference - 1kHz 95% L+R Modulation

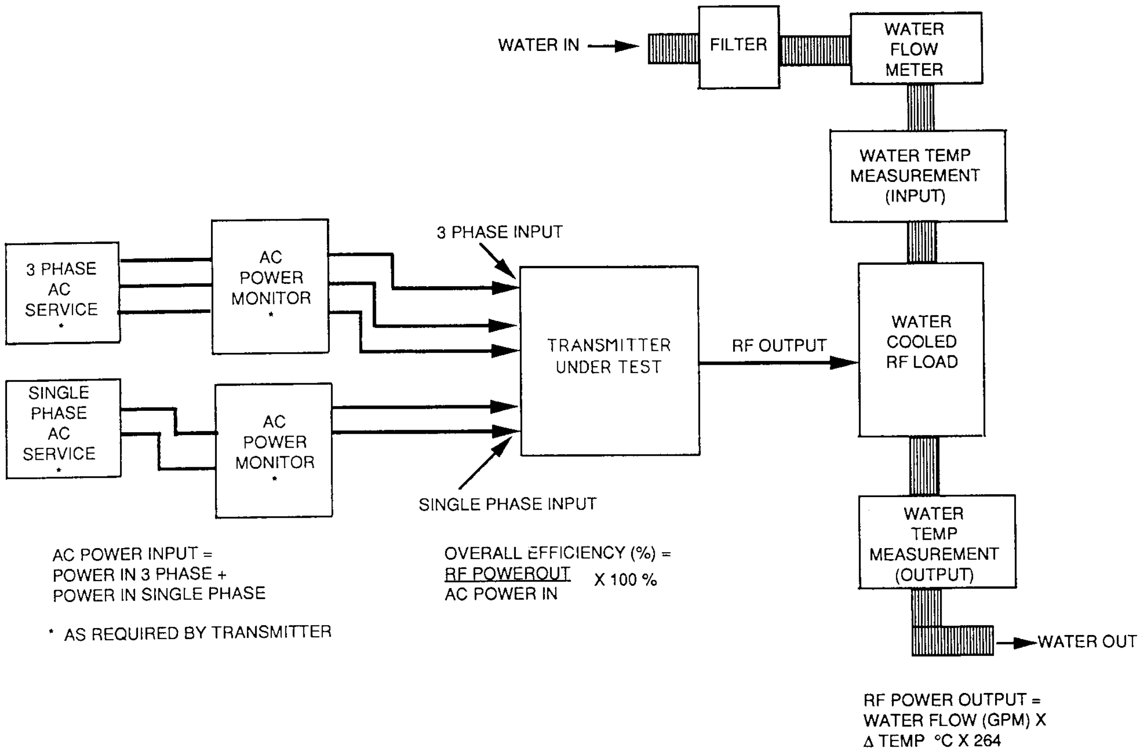


Fig. 6. Overall Efficienty Measurement

Transmitter performance, operating parameters and critical component temperatures are monitored during this testing.

Altitude Testing - Consideration for operation of a transmitter at altitudes must be taken into account at the initial design stages of the product. Operation at high altitudes will have a significant effect on the cooling efficiency of the air system design. With the PA efficiencies now averaging 90% or greater, sufficient cooling headroom can usually be built into the transmitter without impacting cost dramatically. Transmitter altitude specifications will typically allow operation up to 13 000 ft (3962m). Reduced effective clearance of any part that is at high voltages must be taken into account. Utilizing fully solid state designs, voltage clearance of power supplies is no longer a major problem even though output network clearance is still a major consideration.

Ruggedness Testing

Ruggedness testing has always been performed on transmitters used in broadcasting. In many cases it was performed by actual field usage of the transmitter and its subsequent resolving of problems at the test site. With the new generation of solid state transmitters, field conditions can be recreated in the lab in order to identify potential field problems earlier in the transmitter development stage. The purpose of this section is to list the battery of tests that a modern solid state AM transmitter must survive before it is ready for field testing.

Ruggedness Testing (AC Input)

The following tests are performed to simulate expected variations on the incoming power line on both a long and short term basis.

Line Voltage Variation - The typical specification for line voltage variation is from +-5% to +-10%. This specification usually implies that the transmitter will continue to operate normally and meet all performance specifications if the line voltage remains within these limits. Tests are also conducted up to +-20% of line voltage in order to identify potentially unstable or out of design tolerance conditions.

Brownout Testing - The AM transmitter must be able to handle an incoming ac voltage below its specified rated voltage without being damaged by the sustained low voltage. At a certain voltage threshold, the transmitter should conduct an orderly shut down and immediately return to the On-Air condition after the ac voltage has returned to within specified limits. Both brown out and line voltage variation tests are simulated by varying the input voltage by means of a variac, ac generator, or auto transformer.

AC Line Transient Testing - The solid state AM transmitter must be able to withstand the expected amount of transient energy that will appear on the incoming ac feed lines due to storms or other means. The transmitter's protection circuitry must dissipate this energy before it causes damage to internal components. A typical transmitter design will include some basic surge protection in the form of MOV's across the incoming ac lines and lower voltage MOV's on the secondaries of transformers. Zener diode protection is added to each dc supply line.

For testing, a Surge Generator/Monitor rated for the transmitter AC input voltage and current, is connected to the power line as noted in Fig. 7. All transient testing is conducted using ANSI/IEEE C62.45-1987 as a guideline. The types of surges initiated are referenced to ANSI/IEEE C62.41. Any failures are noted and the proper protection installed to the susceptible circuitry.

Electro-Static Discharge (ESD) - ESD testing involves applying a high voltage/low current discharge to the external cabinet of the transmitter under test. This test simulates the action of a person touching the cabinet during dry conditions which could cause a static discharge. The test is set up as in Fig. 8. The transmitter is operated at full output power with high level modulation. The voltage source is set to 10 000 VDC. Using a device such as a transmitter grounding rod, the capacitor C1 is charged through R1. The capacitor is then allowed to discharge to the cabinet. Numerous points on the cabinet are repeatedly tested along with all exposed knobs and buttons. Unusual transmitter action or failure indicates susceptibility to ESD.

Phase Imbalance/Loss Of AC Phase - If using 3 phase ac power, the typically allowed ac phase imbalance is generally from +-2% to +-5%. As the imbalance becomes greater, transmitter performance specifications such as AM noise will degrade. Also in order to protect itself from damage due to overheated motor and transformer windings, the transmitter will usually shut down at a specified imbalance or complete loss of phase. After the imbalance is removed, the transmitter should be able to resume operation.

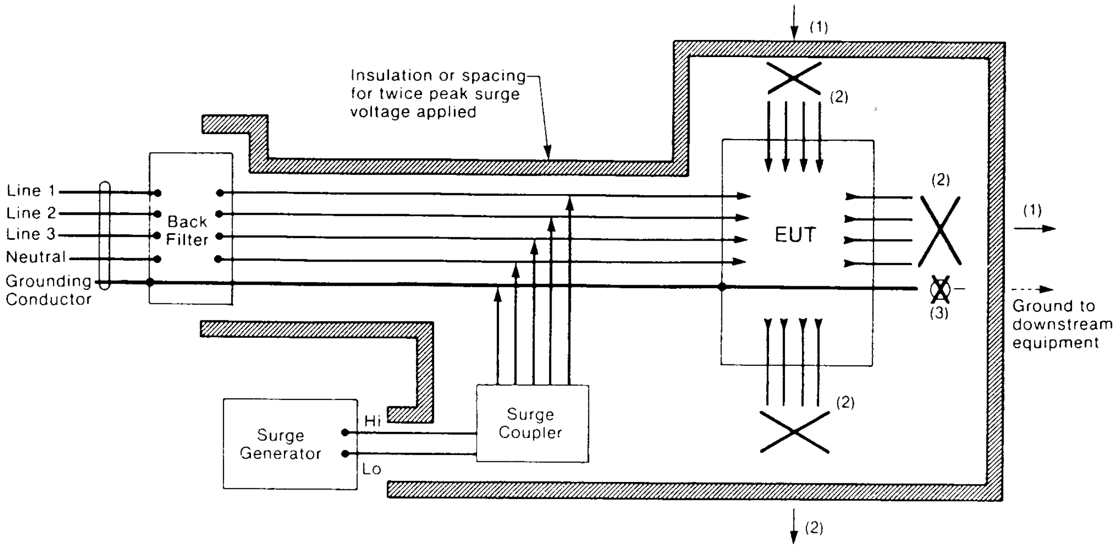
Ruggedness Tests (RF Load Variations)

The following tests are utilized to evaluate the transmitters performance and susceptance to load impedance variations.

Long Term VSWR- This subject discusses load impedance variations that occur over a longer period of time and of less magnitude. The specified output impedance of a modern AM transmitter is typically 50 ohms at j0. At this impedance, the final amplifiers will be operating at their optimum efficiency and loading. Antenna ground system condition and ground conductivity inconsistencies especially on multi-element arrays, can cause variations of the input impedance from the nominal 50 ohms. Therefore there are two tests used to evaluate a modern AM transmitter's ability to operate into non-optimal load impedances.

1. Output Network Tuning Range - In order for the transmitter final amplifiers to operate at their optimum designed loading ratio and reactance, a means of matching the antenna load to the amplifier is needed. This matching network should include easily adjustable components to vary the resistive and reactive values of the output network in order to match the output load impedance(not necessarily 50 ohms resistive) to the transmitter's final amplifier output impedance. Output network tuning range can typically be determined by analysis and modeling. This can then be tested by a setup similar to Fig. 9 with the network component values altered in order to generate mismatches of up to the specified VSWR and at various complex load values. At each selected load value, the operation of the output network matching is verified. A typical output network load matching range is from a 1.3:1 to 1.5:1 VSWR.

2. Ability Of Transmitter To Operate Into Varying Load Impedance- Once the transmitter is tuned into the operating load im-



Notes:

(1) Signal or power conductors, or both, to other equipment

(2) The crosses (✕) indicate one or more of the following:

A. Complete disconnect of the conductors

B. Insertion of a surge filter similar to the back filter

C. Disconnect of the conductors, with addition of a representative termination.

(3) The cross ✕ indicates disconnection of grounding conductors to downstream equipment in order to avoid passing on a surge. However, a grounding connection to that downstream equipment must be re-established, bypassing the EUT test setup.

Fig. 7. Equipment Setup for AC Input Transient Testing [6]

pedance, there is no guarantee that the impedance will not deviate during operation. Antenna system condition, ground conductivity, and weather conditions can cause the load impedance to vary from nominal. As the impedance deviates, transmitter performance, and efficiency may degrade. The transmitter design should take this into account and rate the components in the amplifier to safely operate with a less than optimum output load impedance. There is a limit as to how far the transmitter output impedance can drift from optimum before self protection occurs.

This test is typically conducted in conjunction with the output network tuning range test above. Transmitter operating parameters and performance are measured into a nominal 50 ohm load. When each of the various mismatches are applied, transmitter performance and operating parameters are again measured to determine any significant chances. Then the output network is adjusted to determine tuning range.

High Level Instantaneous VSWR- This refers to any high level VSWR occurring for a short duration of time. An example of this would be a static discharge across guy wire insulators, arc across a component in the antenna system, or any other generated means of VSWR. The optimum type of operation in this condition is for the transmitter to remove carrier just long enough to protect itself and allow the VSWR to clear before reapplying power.

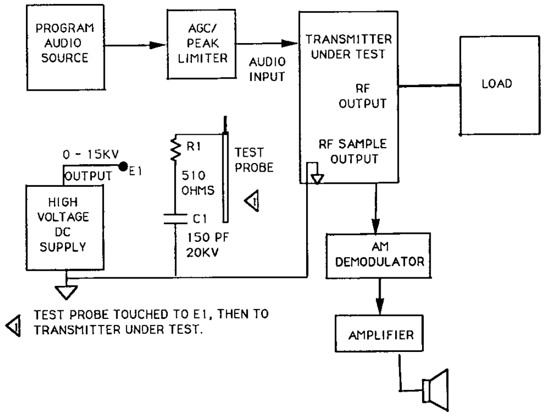
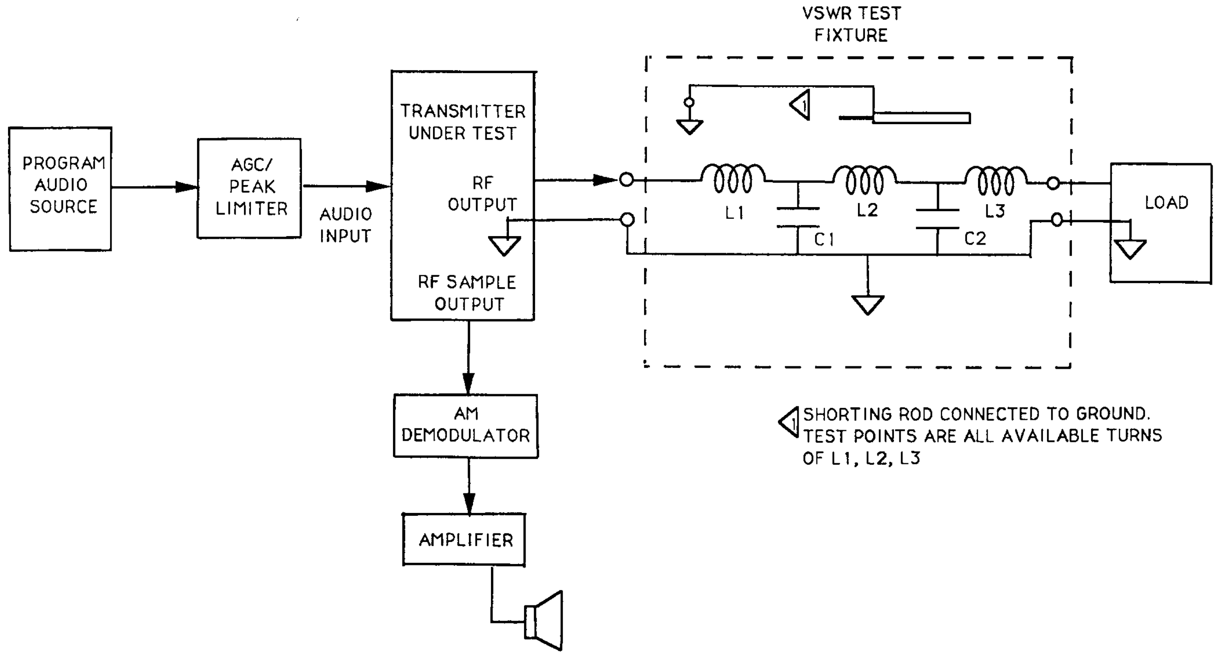


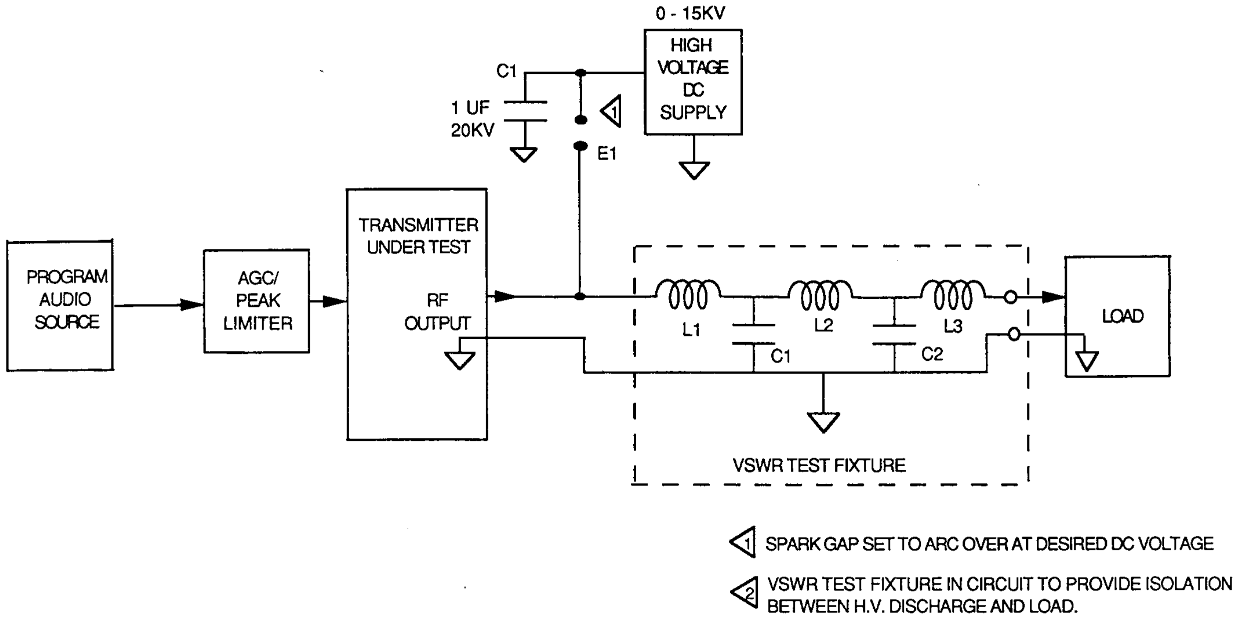
Fig. 8. Electrostatic Discharge Test Setup

Fig. 9 shows the test setup for generating instantaneous VSWR into a transmitter. The network shown is a 50 ohm to 50 ohm matching network. The transmitter under test is operated at maximum rated power with high density, program modulation. A shorting stick is then touched to every available inductor turn in order to simulate as many phases of VSWR as possible. The transmitter should self protect by removing carrier until the VSWR is removed. Additional testing involves allowing each test point to arc to the grounding stick at the transmitters peak output power, when the ground is brought slowly up to each test point.



1 SHORTING ROD CONNECTED TO GROUND.
TEST POINTS ARE ALL AVAILABLE TURNS OF L1, L2, L3

Fig. 9. Test Setup for VSWR Testing



1 SPARK GAP SET TO ARC OVER AT DESIRED DC VOLTAGE

2 VSWR TEST FIXTURE IN CIRCUIT TO PROVIDE ISOLATION BETWEEN H.V. DISCHARGE AND LOAD.

Fig. 10. Setup Diagram for HV Discharge into Output Network

During this testing, the audio programming is monitored and the minimum amount of transmitter carrier off time is varied in order to determine how long the carrier can be off and yet be as unobtrusive to the listener as possible. The actual VSWR threshold at which the protection will activate will also be determined during these tests. Depending on the duration of the VSWR, the transmitter may also include power foldback in order to keep the transmitter on the air during conditions which would not allow operation at higher powers. The desired VSWR foldback threshold is determined during this testing.

High Voltage Discharge Into Output Network

The solid state transmitter should be capable of withstanding a high voltage discharge into the output network of the transmitter. This would occur during a lightning strike on the tower, where the peak voltage on the transmission line must obtain the breakdown voltage of an arc gap located in the antenna system. Before this occurs, the components within the transmitter must be able to withstand the peak voltage without damage. During this instantaneous VSWR, the final amplifiers must also be protected.

See Fig. 10 for test set up. The arc gap is initially set for a 0.25 inch (.6cm) gap. The transmitter is operated at full output power and high level modulation. The current limited, DC voltage source output is slowly increased from minimum. At a certain voltage, the arc gap E1 will break down and allow the DC voltage to be discharged into the transmitter output network. This voltage should be noted and the arc gap increased until the desired breakdown voltage is obtained. Tests have shown that a 10kV to 15kV discharge is sufficient to determine susceptibility.

Conclusion

Measurement technology has had many recent advancements and radio broadcast has seen the results of this progress. Comprehensive tests are used to prove the field worthiness of a transmitter before its introduction into the market. This type of test program has been extremely successful in increasing the overall reliability of new transmitters and reducing the number of initial field problems.

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