GATES ENGINEERING REPORT

FM STEREO PROOF OF PERFORMANCE

HARRIS INTERTYPE CORPORATION

GATES

A STEREO PROOF OF PERFORMANCE

INTRODUCTION

For many years it has been necessary for the engineering staff of a broadcast station to concern itself with the technical standards demanded of its facilities by the Federal Communications Commission. As the state-of-the-art of broadcasting has advanced, so has the complexity of the standards. The purpose in adhering to these standards is the same for both the broadcaster and the F.C.C.: To provide the best possible service to the listener.

This concern for technical standards required of each broadcasting station has manifested itself in the need for a periodic, exacting measurement of the transmitting abilities of each licensed broadcasting station. This measurement has come to be known as a "Proof-of-Performance."

The necessary standards to be met during Proof-of-Performance measurements are well defined in part 73 of the F.C.C. Rules. These standards are set at a point which is demanding of the equipment, but not outside of reason.

Most of the commercially available equipment manufactured today is submitted to the F.C.C. for approval or acceptance under its rules. It is, therefore, reasonable to expect that approved or accepted equipment will deliver performance which will fall within the specifications demanded by the Commission.

At the same time, when Proof-of-Performance measurements are conducted by the broadcasters, many different approved or accepted parts of a broadcasting system are in use. Although the condition of any of the parts of the system may be perfect by official standards, their combination may result in performance of the total system that is either superior or inferior to that which is required. As the complexity of a broadcasting system increases, so does the possibility that the system will not meet the standards prescribed by the rules of the F.C.C.

The most complex aural transmission licensed today is stereophonic FM broadcasting. Therefore, this system is the most susceptible to one or more faults which will cause it to fail to meet the technical standards required.

Stereophonic broadcasting places very exacting requirements on the transmitting equipment itself, as well as the devices used to measure the performance of the transmitting equipment. This paper will attempt to make clear the requirements placed on both the transmitting and measuring equipment necessary to establish proper operation of a stereophonic broadcasting system. It will also discuss the electronic action that takes place in a correctly operating system, as well as what may be wrong in the case of a stereophonic transmission that does not meet the required specifications. This paper will not deal with situations which involve malfunctioning equipment, since it is assumed that the equipment of a broadcasting station should be in operating order before Proof-of-Performance measurements are attempted.

It is the purpose of this paper to provide you with enough information about the content of a correctly generated stereophonic transmission as well as the techniques used in its measurement to enable you to derive a Proof-of-Performance of your system which satisfies the requirements of the F.C.C. as well as fulfilling your own needs for knowing how well your station is performing.

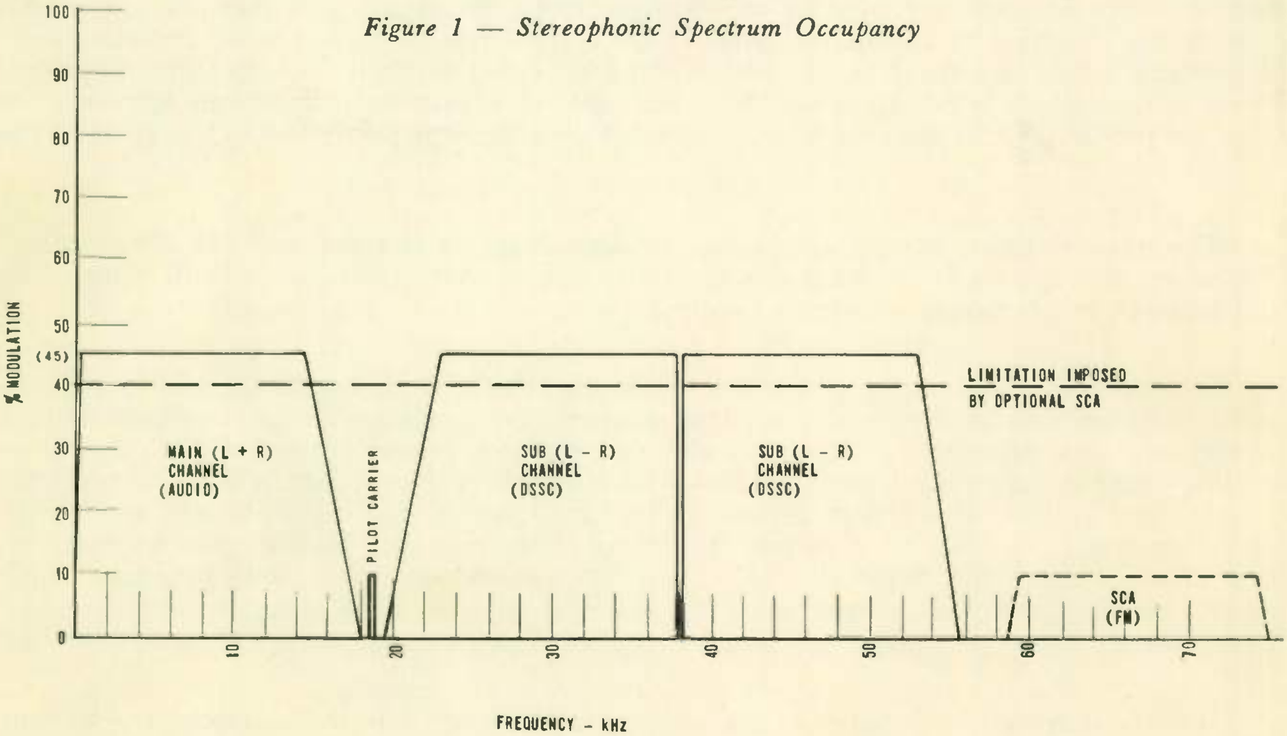
MODULATION

In order to impress audio information on an FM carrier, its frequency must be altered at an instantaneous rate that corresponds to the frequency and amplitude of the modulating waveform. In older FM exciters this was achieved by phase modulating one or more stages in the exciter between the crystal controlled oscillator and the output, which was, of course, at many times the frequency of the crystal, such as in the Gates M-6095 cascade modulated tube type exciter. In most of today's exciters modulation is achieved by directly altering the frequency of a free running oscillator. The center frequency of this oscillator is then controlled within established limits by an automatic frequency control circuit. Gates pioneered the on-frequency modulation technique in the TE-1 solid state exciter which achieved new heights in low distortion. This system is known as "DCFM."

In either system, of course, the result is the same, that is, the output frequency changes at a rate that corresponds to the modulating frequency and amplitude. In the case of monaural operation, this modulating frequency is simple audio.

In the stereo system on the other hand, the audio component is there, but additional material modulates the exciter. This additional material consists of a pilot frequency of 19 kHz as well as various frequencies grouped around 38 kHz. These latter frequencies are sideband products of a second audio channel which is actually the result of creating an amplitude modulated double sideband suppressed carrier signal with 38 kHz being the frequency of the suppressed carrier. All of these modulating frequencies, which actually occupy a bandwidth up to 53 kHz, when considered together, are known as a composite stereo signal. In addition, a sub-carrier may occupy the spectrum above 53 kHz. The spectrum distribution may be seen in Figure 1. Note that when the modulation percentages of the spectrum components are added, they equal 100%. More will be said about this later.

Figure 1 — Stereophonic Spectrum Occupancy



As we mentioned before, the composite stereo signal is composed of three basic parts, an ordinary audio frequency channel, a pilot frequency and 38 kHz double-sideband suppressed-carrier signal. The purpose of each of the three parts is unique.

In the F.C.C. approved system the ordinary audio channel carries both the left and right audio signals of a stereo signal, so that listeners with monaural receivers are able to receive all the program material transmitted by a stereo station. Therefore, in a composite stereo signal the left and right stereo signals are added and used to modulate the ordinary audio channel. This channel is known as the L+R or **main-channel.**

Now that the main channel is successfully modulated with the total program material so that compatibility with monaural receivers is assured, it is necessary to provide stereo receivers with enough information for them to be able to sort out the two distinct stereo channels and send them to the proper outputs. To achieve this end, the left and right stereo channels are once again combined, but this time they are **subtracted.** or in electronic terms, the **phase** of the right channel is reversed. This new representation of the two stereo channels is then used to modulate the double-sideband suppressed-carrier signal, which is called the L–R or **stereo sub-channel.**

Since it is evident that the generation and sorting out of the composite signal is reliant on knowing the phase relationships of the left and right stereo signals in both the main and sub-channels, the purpose of the pilot signal becomes clear. It is the reference that both the transmitter and the receiver use to arrange the stereo channels in their proper places. All transmitter exciters generate a composite signal in which zero crossing of the pilot signal occurs at precisely the same time that positive going zero crossing of the suppressed 38 kHz carrier occurs.

There are two popular methods of generating the L+R main-channel and L–R sub-channel. One method employs an audio matrix to perform the signal addition and subtraction before modulation, while the other system uses 38 kHz switching in the modulator itself. The end result is the same for either system, except that the switching method generates harmonics which must be suppressed before the composite signal is used to modulate the transmitter. All type-accepted exciters have this necessary suppression.

Since the main channel and the sub-channel, as well as the pilot signal modulate the transmitter, it is important to know the relative modulation percentage of each. The standards now employed demand that the pilot signal modulate the transmitter between 8 and 10 percent, and for all practical purposes, this is 10 percent. Since the **total** modulation of the transmitter cannot exceed 100 percent, it becomes clear that any combination of main and sub-channel modulation cannot exceed 90 percent without SCA. These relationships become more clear in the process of actual Proof-of-Performance measurements.

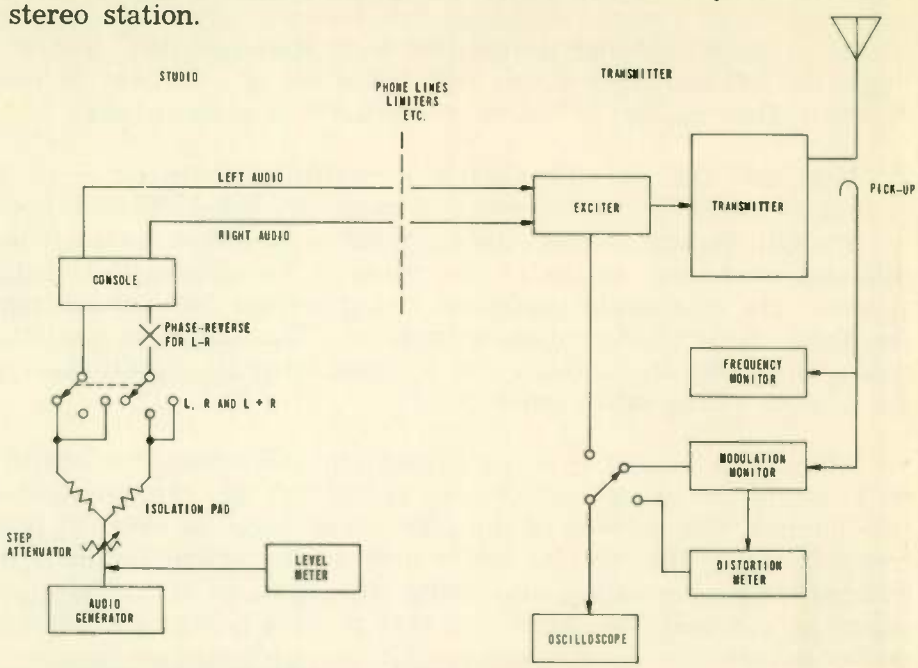
In short, when analyzing a stereo signal, it is important to understand all of the material in the composite signal. Proper use of an oscilloscope and measuring equipment will reveal where deviations from the ideal in a composite signal are occurring. The nature of these deviations will give a clue as to the problem.

Analyzing the stereo signal requires a type-approved modulation monitor and a good oscilloscope. By this it is meant an oscilloscope capable of square wave reproduction to at least 200 kHz, and whose probe is properly equalized if such equalization is provided. Any oscilloscope not meeting these specifications will provide erroneous patterns relating to separation and certain other patterns cannot be reproduced clearly.

The modulation monitor uses a wideband FM detector to derive an accurate replica of the composite signal being transmitted, and then processes it further to provide the left and right stereo outputs. Both the composite and audio outputs of the monitor are of importance. The left and right audio outputs are used in a conventional manner to measure such standards as frequency response, distortion and noise. The composite output, on the other hand, is attached to the oscilloscope in order that conditions affecting crosstalk, separation and 38 kHz carrier suppression may be observed.

Fig. 2 is a block diagram showing a set-up of equipment that is satisfactory for establishing the performance of a stereo station.

Figure 2 — Block Diagram - Stereo Proof of Performance



THE PROOF-OF-PERFORMANCE SET-UP

So far as audio frequency response, distortion and noise are concerned, the procedure for measurement is identical to a monaural FM Proof of Performance, except that everything is done twice . . . once for each stereo channel. The procedure for these types of measurements has been well covered elsewhere, and the standards to be met are a part of the F.C.C. Rules. Assuming all parts of a transmitting system are performing correctly, the total system should meet all frequency response, distortion and noise requirements. If requirements are not met, the cure can be found in measuring the individual parts of the system, and determining where the fault lies.

For the purpose of frequency response measurements it is necessary to insert a standard level signal into the input of the studio audio system, insert a proper amount of attenuation to prevent overload, and then measure the amount of signal necessary to create a given modulation percentage. The frequency of the signal should then be set to the other values required, and the amount of attenuation needed to maintain the same modulation percentage noted. The results can be charted on a curve to see that they correspond with the requirements of the pre-emphasis curve shown in part 73 of the Rules.

Distortion measurements may be taken at the same time by using the distortion meter connected to the output of the modulation monitor used to take the frequency response measurements. This same distortion meter may be used to measure noise in the system after the removal of modulation.

It should be noted that the F.C.C. requires distortion measurements of a fundamental modulating frequency up to 15 kHz. Such measurements with equipment commonly available today are actually impossible in stereo operation, since low-pass filters are used in stereo modulation monitors which eliminate all frequencies above 15 kHz. Since distortion meters operate by detecting harmonics generated by distortion, they can't very well detect these harmonics if they have been filtered out. Strict adherence to the rules demands that distortion measurements above 7500 Hz should be taken, but the engineer should be aware that when he takes these measurements they are not a true representation of any harmonic distortion that may be present. However, a fairly good feeling for the operation of the system can be gained by distortion measurements taken just below 7500 Hz since the second harmonics of these frequencies will fall below the 15 kHz point.

SEPARATION AND CROSSTALK MEASUREMENTS

The terms separation and crosstalk seem to mean the same thing. Nothing is farther from the truth. Separation really means the perfection with which the system keeps left channel audio out of the right channel, and vice versa. Poor separation can usually be traced to leakage from one audio channel to the other in the studio or improper adjustment of the pilot phase of the transmitter and/or the modulation monitor. It can also be traced to improper main and sub-channel gain relationship. This relationship should be 1:1.

Crosstalk is a completely different specification. There are really two different types of crosstalk . . . system crosstalk, and transmitter crosstalk. The definition of crosstalk is the amount of main channel modulation that appears in the sub-channel and vice versa. Since this is a matter of how much L+R appears in the L−R channel, and vice versa, high crosstalk does not **necessarily** mean that there will be poor separation.

Knowledge of system crosstalk is important to the broadcaster, since poor system crosstalk means that there will be a degradation of the phase relationships of the left and right channels as received by the listener. A degradation of these phase relationships leads to a loss of realism in stereo sound, even though separation may be good. So, it is in the interest of the broadcaster to keep system crosstalk as low as possible.

There is only one accepted way of measuring system crosstalk; connect an audio generator to the left and right audio inputs of the system. These inputs should be paralleled either in-phase or out-of phase to insure equal driving amplitudes for the left and right channels. The resultant driving signals are known as L equals R and L equals −R respectively. This results in modulation of either the main or the sub-channel only with no modulation appearing in the other (assuming there is no crosstalk). For this to occur, the signals throughout the system must be **precisely** the same in amplitude and be either precisely in phase or precisely 180 degrees out of phase. Any deviation from this preciseness will result in crosstalk.

It can be seen that crosstalk can take the form of imperfect operation of the stereo transmitter itself or an imperfection of equipment used before the transmitter, such as phone lines, limiters and consoles. When the latter imperfection is the case it contributes to system crosstalk (crosstalk in the transmitter based on system performance) whereas a weakness in the transmitter itself creates only transmitter crosstalk. It is important that the broadcaster differentiate between system and transmitter crosstalk. Although the effects are the same, the causes are quite different. In the event the broadcaster experiences an undesirable amount of crosstalk, before a cure can be found, he should determine which form of crosstalk it is.

Crosstalk in a transmitter, assuming the proper phase and amplitude relationships exist in the system prior to the inputs of the exciter, is mainly due to intermodulation distortion. This distortion can be introduced by misadjustment of the exciter, excessively high "Q" tuned circuits in various transmitter stages, poor neutralization of amplifier stages and antennas with poor bandwidth. All of these should be checked, and their effects on crosstalk minimized by tuning or adjustment, if necessary. In some cases controls of transmitters can be used to adjust for minimum crosstalk as well as to control the output of the transmitter. Proof-of-Performance time is a good opportunity to observe this phenomenon and learn to tune the transmitter effectively in regard to crosstalk.

Aside from crosstalk introduced by transmitter deficiencies, system crosstalk is most often caused by unequal gains or phase shifts in the two audio channels. The most frequent phase shift offenders are telephone lines used by stations that operate with studios located remotely from transmitter. Running a close second are the phase shifts and gains introduced by small differences in A.G.C. and Limiting amplifiers especially if these amplifiers are not of an identical type. The cure for these problems is diligence on the part of the broadcaster concerning the quality of telephone service he is provided, and an attention to component selection in the various amplifiers used to create equal phase shift through each channel. If the amplitude and phase relationships between left and right channel do not remain constant within approximately 1 percent and 1 degree through a system, it is mathematically impossible for the broadcaster to meet crosstalk specifications, assuming the transmitter is perfect . . . which it probably is not.

In some cases, both poor separation and excessive crosstalk can be caused by the effect of an RF amplifier with insufficient bandpass characteristics placed in the measuring circuit ahead of the modulation monitor. For this reason it is recommended that Proof-of-Performance measurements be taken with the modulation monitor located at the transmitter site and the RF amplifier disconnected.

MECHANICS OF MEASURING SEPARATION AND CROSSTALK

Before either separation or crosstalk is measured, it is necessary for the pilot phase, and amplitude to be correct. In addition the main channel and sub-channel gain must be precisely equal. It goes without saying that the system gain and phase shift between the right and left audio channels should be kept on a one to one basis.

For the purpose of setting the pilot gain and phase, the inputs to the transmitter exciter (left and right) should be connected in parallel, but out of phase. A tone of approximately 50 Hz should then be applied to these paralleled inputs. Under these conditions what is known as an L equals minus R signal is being applied to the exciter. Assuming the pilot gain setting is correct, and the pilot is modulating the carrier between 8 and 10 percent, a pattern like that shown in Fig. 3 should be observed on an oscilloscope connected to the composite output of the exciter in the transmitter, in this case a Gates FM-20H2. If the pilot phase control is mis-adjusted, a pattern such as Fig. 4 or Fig. 5 will result. If this is the case, readjust the pilot phase until a pattern such as Fig. 3 results. It may be necessary to readjust the pilot

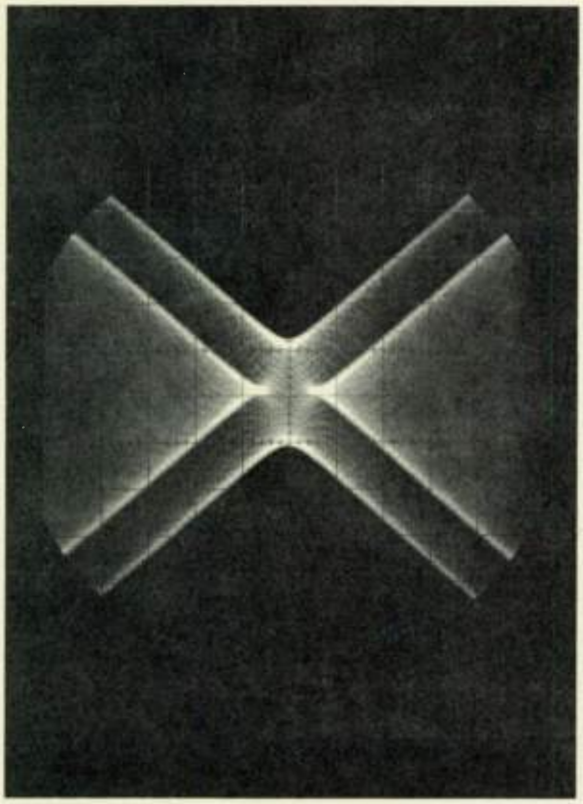


Figure 3

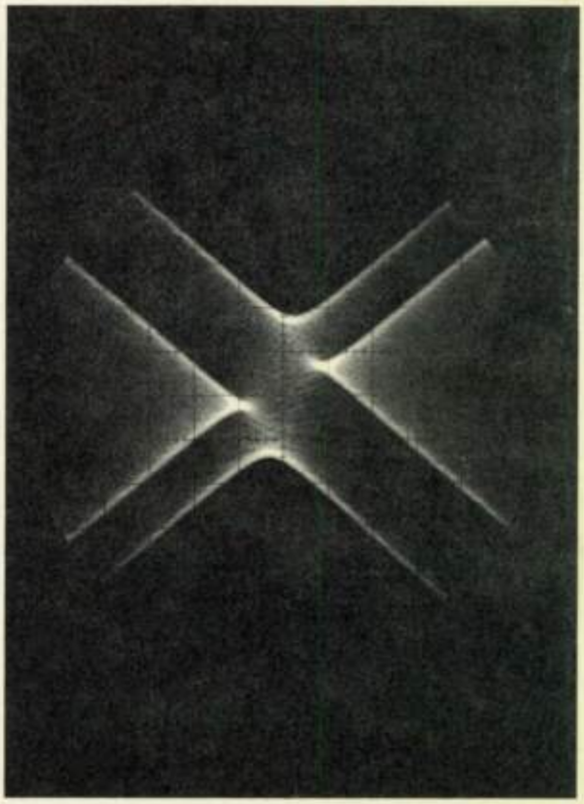


Figure 4

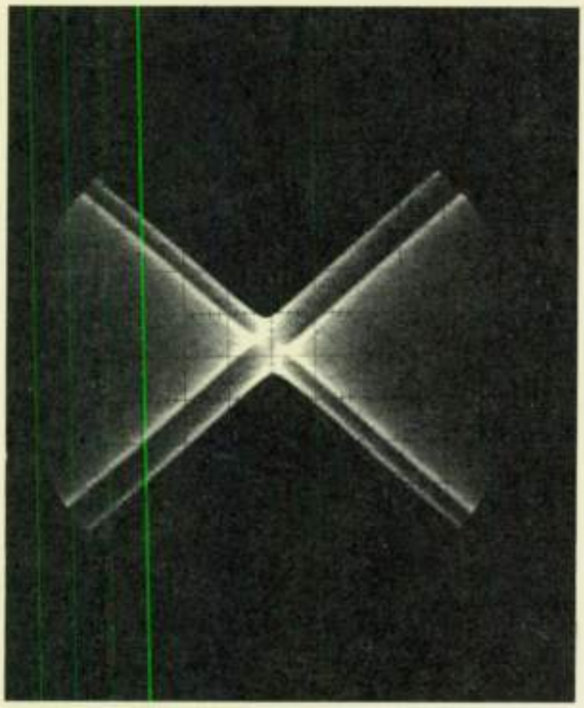


Figure 5

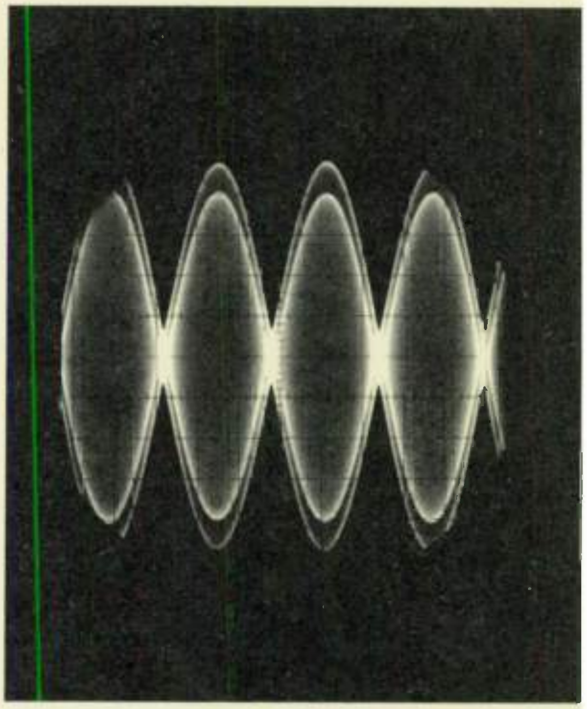


Figure 6

gain control each time the pilot phase is adjusted, but eventually the Fig. 3 pattern will be arrived at with the correct pilot modulation percentage occurring at the same time.

Once this adjustment has been achieved it is time to move the oscilloscope to the composite output of the modulation monitor. The display on the oscilloscope will now be identical to that observed directly from the composite output of the transmitter's exciter, assuming that the monitor is operating correctly. With the same signal conditions present, adjust the pilot phase control on the monitor according to the instructions of the manufacturer. From this point on, do not adjust either the exciter or the monitor pilot phase control.

For reference, when the pattern shown in Fig. 3 is diminished to the point that all of it may be seen on the oscilloscope screen it will look like the pattern shown in Fig. 6, which is the classic stereo L − R "butterfly."

The next step is to disconnect the input set-up of L equals − R. Connect a 400 Hz signal into the left audio channel input of the exciter. The resultant oscilloscope pattern will resemble Fig. 7, as taken from a Gates GTM-88S Modulation Monitor. If the L + R gain of the exciter exceeds or is less than the L − R gain the result will be a pattern similar to Fig. 8. If such is the case, adjust the gain controls to flatten out the base line so that it resembles Fig. 7 as closely as possible. Some exciters provide gain controls for both L + R and L − R, while others provide only L + R gain control. This is unimportant, since the object is to get the two gains equal relative to each other. It is important to note that should the **right** channel audio input be used instead of the left, the results will be the same except that the oscilloscope pattern may be inverted depending on what type of sync triggering is used. Assuming that the system has been adjusted properly with the oscilloscope, to measure separation it is merely necessary to modulate the transmitter 100% as indicated in the **total** position of the modulation monitor by providing the transmitter with a signal at any given audio frequency in either the left or right input. The separation in dB may then be read from the modulation meter in the opposing channel position. Crosstalk is a bit trickier to measure. The first step is to connect the left and right stereo channels in parallel and **in phase** and drive the exciter

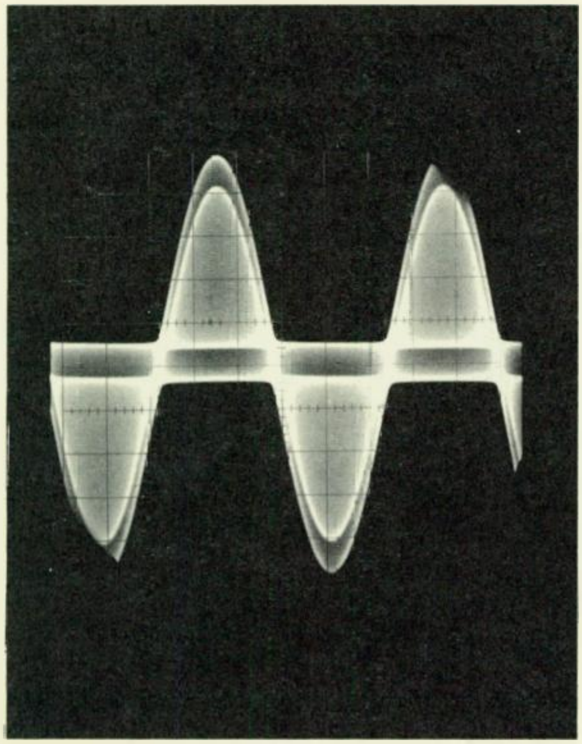


Figure 7

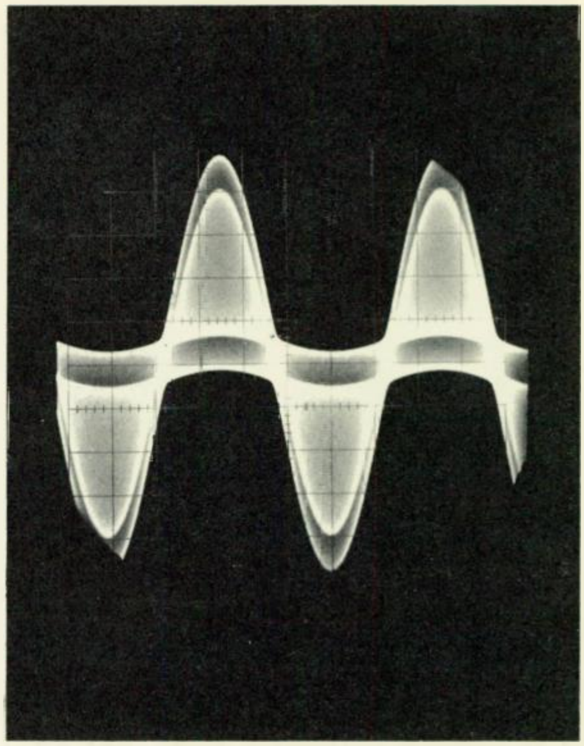


Figure 8

with the desired frequencies at which crosstalk is to be measured. This will result in modulation of the main (L + R) channel with no modulation of the sub (L − R) channel. Thus, any indicated modulation of the sub-channel will be a representation of crosstalk. It is important that this measurement be calibrated by modulating the **main** channel 90 percent (90% main plus 10% pilot equals 100% total). Do not modulate the main channel 100% by mistake believing it to be a representation of total modulation. Crosstalk, main into sub may now be read on the modulation monitor in the "sub" or L − R position.

Next, reverse the phase to the right channel and reverse the procedure, setting sub, or L − R modulation percentage to 90%. Crosstalk may now be read in the "main" or L + R position.

Don't forget: Failure to meet crosstalk specifications may be based on any number of things. Each possible cause should be examined separately. A crosstalk measurement should be run through the transmitter alone to determine the correct adjustments in the stereo exciter, the tuning controls of the transmitter, and neutralization if necessary. The second step is an analysis of phase and amplitude shifts through the system prior to the transmitter, and a correction of their deficiencies where necessary. Although crosstalk specifications are the most difficult of any to meet in a stereophonic system, once met, they guarantee added realism and fidelity to the broadcast. This will make the time and effort spent worthwhile.

OTHER MEASUREMENTS

Of interest is the oscilloscope pattern shown in Fig. 9. This is a picture of the composite signal generated by a L equals R or main channel 400 Hz tone. Since an L equals − R signal does not exist when L equals + R only is created, all that shows here is the modulating frequency plus the pilot. Because of the relative width of the trace lines vs the peak to peak dimension of the modulating 400 Hz tone, it is relatively easy to calculate the modulation percentage of the pilot and check it against that indicated by the monitor, assuming the oscilloscope is accurate.

Fig. 10 shows a rare case. A phase shift between the L + R and the L − R channels is occurring within the stereo exciter **after** the audio matrix has sorted these signals. There are adjustments for this phase shift inside stereo exciters, which normally should not be touched, but in the case of a situation demonstrated by Fig. 10, they should be investigated.

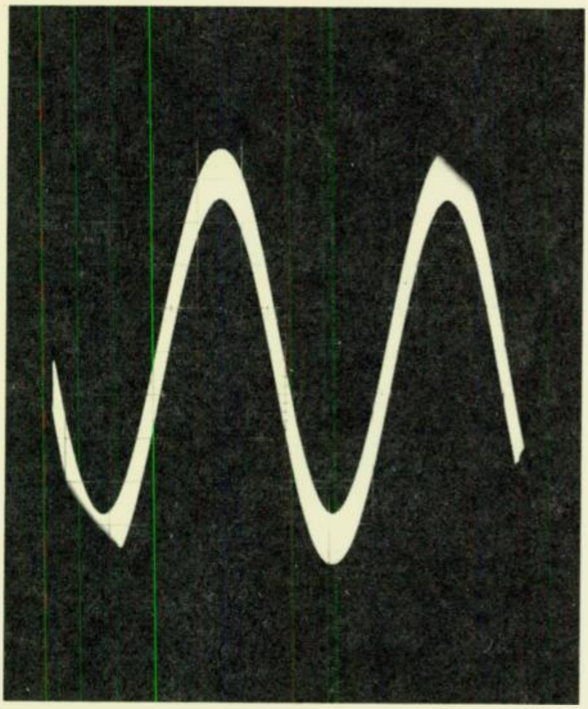


Figure 9

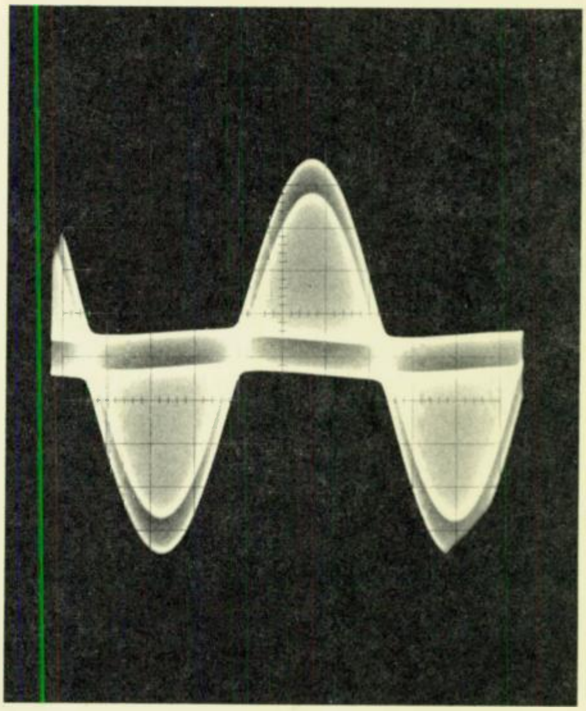


Figure 10

Current specifications require that the 38 kHz sub-carrier itself modulate the stereo transmitter by no more than 1 percent. This corresponds to a suppression of 40 dB and can usually be measured on the modulation monitor itself. Current requirements are that this suppression hold true for both modulated and unmodulated conditions. Some modulation monitors are unable to measure 38 kHz sub-carrier suppression if the modulating frequency on the sub-carrier is lower than 5 kHz. If measurement of 38 kHz suppression is desired with modulating frequencies below 5 kHz, a panoramic oscilloscope or similar device is required.

Along the same lines, various extraneous signals present in a composite stereo signal can easily be identified by use of an oscilloscope attached to the instrument output of the modulation monitor, as well as the output of the distortion meter. In this latter case the distortion meter is used as a tunable filter during modulation to remove the basic modulating frequency and leave the remaining signals for observation. Identification of the frequency and waveform of these noises and signals can give a clue to their origin, and ultimately their elimination, if they are spurious and of an undesirable nature.

Finally, there is a requirement for the measurement of AM noise on the FM signal as broadcast by a stereo station. The procedure for measuring this is the same as that for a monaural station. However, many times instructions are somewhat unclear. The proper method is to follow the instructions of the manufacturer of the modulation monitor that is used, with the understanding of what is really required when AM noise is measured. What is happening is this: First, the DC voltage created by diode detection of the incoming RF signal is established. If this incoming signal were 100% modulated, the audio (or AC) signal that would be derived from this diode detector through a coupling capacitor would be 1.414 times the DC voltage present. Since an AM noise figure of ⁻ 50 dB is required, this is the same as saying that the AC RMS voltage at the output of the diode detector of the modulation monitor should be 50 dB below 1.414 times the DC voltage that is present. This amounts to about .0045 times the DC voltage.

SUMMARY

Step-by-step information on how to run a Proof-of-Performance already exists in material written by the N.A.B. as well as many articles that have been published by broadcasting trade magazines. For this reason, we have not presented such detailed information here. The purpose of this paper was to recognize some of the more complex problems that might confront the engineer attempting to run a Proof-of-Performance, and to answer some of the questions that might arise as to why a broadcasting system might not perform as expected, even though all of the equipment in the system appears to operate as it should.

It has been shown that stereophonic transmission is a complex process with exacting specifications. Gates Radio Company hopes that the information contained in this paper will enable the broadcaster to more easily meet these specifications and benefit from the greater quality of transmission that will result as well as satisfying all the F.C.C. requirements.

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