# Techniques for Measuring Synchronous AM Noise in FM Transmitters

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# TECHNIQUES FOR MEASURING SYNCHRONOUS AM NOISE IN FM TRANSMITTERS

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## INTRODUCTION

This paper presents an explanation of synchronous AM noise caused by FM modulation of limited bandwidth systems. Synchronous AM noise is presently one of the "hottest" topics among FM and TV-Stereo broadcast engineers. The causes of this type of incidental AM modulation in the presence of FM modulation are reviewed with emphasis on the practical application of synchronous AM noise measurements to optimize transmitter tuning.

The value of synchronous AM measurements in evaluation the transmission system as well as test equipment selection, system set-up, and interpretation of results are explained. The type of equipment and measurement procedure used can lead to incorrect results. The author explains how to avoid these "pitfalls" so that the station engineer has confidence that the measured results are correct.

It is hoped that this paper will be a valuable reference that broadcast engineers can use to improve the operation of their transmitter systems.

## TWO TYPES OF AM MODULATION

2The perfect FM transmitter would have an absolutely constant output, regardless of FM modulation or power supply variations. In practice, there is always some residual amplitude modulation of the FM transmitter output. There are two types of AM modulation that are of interest to the FM broadcast engineer:

1. Asynchronous AM modulation is measured <u>without</u> FM modulation and is primarily related to power supply ripple or filament supply imbalance. This is the only type of AM noise measurement that is required by the FCC.

2. Synchronous AM modulation (incidental AM) measured with FM modulation is related to the tuning and overall bandwidth of the system. Synchronous AM noise is not a concern of the FCC.

Asynchronous AM

Residual amplitude modualtion of the transmitter output, due primarily to power supply ripple, is measured with an AM envelope detector. Most FM modulation monitors include an AM detector for this purpose. This detector should include 75 microsecond de-emphasis on its output. The residual AM noise in a properly operating FM transmitter will be at least 50 dB below the level which would represent 100 percent amplitude modulation of the carrier. If the transmitter is unable to meet the 50 dB requirement, the problem can usually be traced to a power supply component including the filament supply or to line imbalance in a three phase system.

Synchronous AM

Synchronous AM is a measure of the amount of incidental amplitude modulation introduced into the carrier by the presence of FM modulation. This measurement is very useful for determining the proper tuning of the transmitter. Since all transmitters have limited bandwidth, there will be a slight drop-off in power output as the carrier frequency is swept to either side of the center frequency. This slight change in RF output level follows the waveform of the signal being applied to the FM modulator causing AM modulation in synchronization with the FM modulation. The concept is similar to the slope detection of FM by an AM detector used in conjunction with tuned circuit.

Both types of AM noise measurements are made directly at the transmitter output (or an accurate sample of its output). No amplifying or limiting equipment may be used between the transmitter output and the AM detector since nonlinearities in this equipment could modify the AM noise level present. Since the transmitter cannot be fully amplitude modulated, an equivalent reference level must be established indirectly by a measurement of the RF carrier voltage.

Refer to the instructions of the detector manufacturer to determine this reference level. Generally, the reference level is determined by setting a carrier level meter to a specified reading or to obtain a specific DC voltage level at the output of the detector diode without modulation.

## WHY IS SYNCHRONOUS AM IMPORTANT?

Measurement of synchronous AM gives the station engineer an idea of the overall system bandwidth and whether the passband is positioned correctly. Tuning for minimum synchronous AM will assure that the transmitter passband is properly centered on the FM channel.

### How Does Tuning Affect The FM Sidebands?

The higher order FM sidebands will be slightly attenuated in amplitude and shifted in phase as they pass through the final amplifier stage. These alterations in the sideband structure that are introduced by the amplifier passband, result in distortion after FM demodulation at the receiver. The amount of distortion is dependent on the available bandwidth versus the modulation index being transmitted. For a given bandwidth limitation, the distortion can usually be minimized by centering the passband of the amplifier around the signal being transmitted. This will cause the amplitude and phase errors to affect both the upper and lower sidebands equally or symmetrically. Tuning an amplifier for minimum plate current or for best efficiency does not necessarily result in a centered passband. One way to center the passband is to tune the amplifier for minimum synchronous AM modulation while appling FM modulation to the transmitter.

### How Good Should Synchronous AM Be?

Synchronous AM of 40 dB or more below equivalent 100% AM, is considered to be acceptable. Higher levels of synchronous AM will cause increased "chopping" of the signal at the receiver near limiting threshold under weak signal "fringe area" conditions and can exacerbate multipath problems. Excessive synchronous AM is also an indirect indication of passband induced distortion problems that degrade stereo performance and SCA crosstalk.

Many of the older mult-tube transmitter designs presently in use will have as much as 6% (-30 dB) synchronous AM when simply tuned for best power output and efficiently even though the asynchronous AM (without modulation) may be better than -50 dB. Some of the newer single tube transmitters can be adjusted for 50 dB or more suppression of synchronous AM. The synchronous AM level of virtually any FM transmitter can be improved by proper tuning techniques. An approximation to the overall system bandwidth can be related to the synchronous AM as shown in Table 1.

APPROXIMATE SYSTEM BANDWIDTH AS RELATED TO SYNCHRONOUS AM

| SYNCHRONOUS AM (below equivalent 100 % AM (with ±75 kHz @ 400 Hz FM) | APPROXIMATE BANDWIDTH OF TRANSMITTER (-3dB) | RF LEVEL VARIATION AT RECEIVER LIMITER (%) | (dB) |
|---|---|---|---|
| -30 dB | 410 kHz | 6.32% | 0.57 dB |
| -35 dB | 550 kHz | 3.54% | 0.31 dB |
| -40 dB | 730 kHz | 2.00% | 0.18 dB |
| -45 dB | 1.00 MHz | 1.12% | 0.10 dB |
| -50 dB | 1.34 MHz | 0.64% | 0.06 dB |
| -55 dB | 1.82 MHz | 0.36% | 0.03 dB |
| -60 dB | 2.46 MHz | 0.20% | 0.02 dB |

TABLE 1.

## TUNING YOUR TRANSMITTER FOR PEAK PERFORMANCE

All optimization should be done with any automatic power control (APC) system disabled so that the APC will not chase the adjustment in an attempt to keep the output power constant. The transmitter should be connected to the normal antenna system rather than to a dummy load. This is because the resistance and reactance of the antenna will be different from the dummy load and the optimum tuning point of the transmitter will shift between the two different loads. The tuning sequence is:

### Inital Tuning And Loading

The transmitter is first tuned for normal output power and proper efficiency according to the manufacturer's instruction manual. The meter readings should closely agree with those listed on the manufacturer's final test data sheet if the transmitter is being operated at the same frequency and power level into an acceptable load.

### Input Tuning And Matching

The input tuning control should first be adjusted for maximum grid current and then fine tuned interactively with the input matching control for minimum reflected power to the driver stage. Note that the point of maximum grid current may not coincide with the minimum reflected power to a solid state driver. This is because a solid state driver may actually output more power at a certain complex load impedances than into a 50 ohm resistive load. The main objective during input tuning is to obtain adequate grid current while providing a good match (minimum reflected power) to the coaxial transmission line from the driver. In the case of an older transmitter with a tube driver integrated into the grid circuit of the final amplifier, the driver plate tuning and the final grid tuning will be combined into one control which is adjusted for maximum grid control.

Output Tuning

The output tuning control adjusts the resonant frequency of the output circuit to match the carrier frequency. As resonance is reached, the plate current will drop while both the output power and screen current rise together. Under heavily loaded conditions this "dip" in plate current is not ver pronounced, so tuning for a "peak" in screen current is often a more sensative inidicator of resonance.

Amplifiers untilizing a folded halfwave cavity will display little interaction between output tuning and output loading because the output coupling loop is located at the RF voltage null point on the resonant line. Quarterwave cavities will require interactive adjustments of output tuning and output loading controls, since changes in loading will also affect the frequency of resonant line.

Output Loading

There is a delicate balance between screen voltage and output loading for amplifiers utilizing a tetrode tube. Generally there is one combination of screen voltage and output loading where peak efficiency occurs. At a given screen voltage, increasing the amplifier loading will result in a decrease in screen current, while a decrease in loading will result in an increase in screen current. As the screen voltage is increased to get more output power, the loading must also be increased to prevent the screen current from reaching excessive levels. Further increases in screen voltage without increased loading will result in a screen overload without an increase in output power.

Automatic Power Control Headroom

Automatic power control (APC) feedback systems are utilized in many transmitters to regulate the power output around a predetermined setpoint with variations AC line voltage or changes in other operating paramenters. Most modern FM broadcast transmitters utilize a high gain tetrode as the final amplifier stage with adjustment of the screen voltage providing fine adjustment of the output power.

For each power output level there is one unique combination of screen voltage and output loading that will provide peak operating efficiency. If the screen voltage is raised above this point without a corresponding increase in loading, there will be no further increase in power output with rising screen voltage and screen current. If the screen voltage is raised without sufficient loading, a screen current overload will occur before the upward adjustment in power output is obtained.

To avoid this problem, it it a good idea to tune the transmitter with slightly heavier loading than necessary to achieve the desired power output level in order to allow for about 5% headroom in adjusted range. The output loading can be adjusted for a "peak" in output power of 5% over the desired level and then the screen voltage can be reduced enough to return to the desired level. This procedure will allow headroom for an APC system controlling screen voltage and will result in about a 1% compromise in efficiency, but it will assure the ability to increase power output up to 5% without encountering a screen overload.

## MINIMIZING SYNCHRONOUS AM

After the correct loading point has been set, FM modulate 100% ($\pm$75 kHz) at 400 Hz and fine-adjust the transmitter's input tuning and output tuning controls for minimum 400 Hz AM modulation as detected by a wideband envelope detector (diode and line probe). The input matching and output loading controls should need no further adjustment at this point. It is helpful to display the demodulated output from the AM detector on an oscilloscope while making this adjustment. The output of the AM envelope detector should be connected to the vertical input (Y input) of the scope while the sweep is triggered by a sample of the 400 Hz audio tone fed to the external trigger input. This is called the "AM WAVEFORM" measurement. Note that as the minimum point of synchronous AM is reached, the demodulated output from the AM detector will double in frequency form 400 Hz to 800 Hz, because the fall-off in output is symmetrical about the center frequency causing the amplitude variations to go through two complete cycles for every one FM sweep cycle. This effect is illustrated in Figure-1.

The advantages of observing the demodulated AM waveform versus time, is the frequency doubling effect is a sensative, clear, indication of symmetrical tuning point and the actual level of the AM noise below equivalent 100% AM modulation can be calculated from the waveform's AC and DC components. The disadvantage of this measurement technique, is that it cannot be performed with normal program audio present.

If it is necessary to touch-up the transmitter tuning with normal program audio present, an X - Y display of demodulated AM on the vertical axis (Y input) versus the audio input to the FM exciter on the horizontal (X input) axis, will provide a representation of the transmitter's passband as shown in Figures - 2A and 2B. This is called the "PASSBAND" measurement. Figure - 2A shows the relative amplitude of the transmitter's output power versus deviation from the center frequency with single tone 400 Hz modulation. Figure - 2B shows the same information except that complex program modulation is present

# SYNCHRONOUS AM WAVEFORMS AND CALCULATIONS

DIRECT MEASUREMENT OF SYNCHRONOUS AM NOISE USING A HALF WAVE PRECISION ENVELOPE DETECTOR AND OSCILLOSCOPE.

$$\text{VOLTAGE RATIO} = \left[\frac{\text{ACp.p VOLTS (AC MODULATION)}}{\text{2X DC VOLTS (RECTIFIED CARRIER)}}\right]$$

$dB = 20\ LOG_{10}(\text{VOLTAGE RATIO})$
(BELOW 100% EQUIV AM)

$\%AM = 100 \times (\text{VOLTAGE RATIO})$

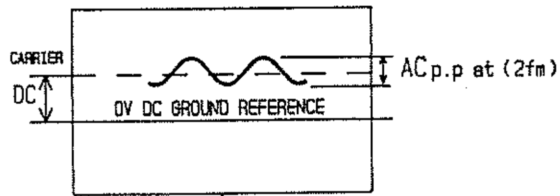
EXAMPLE:

RECTIFIED CARRIER DC = 940MV
AC MODULATION AC = 4.6MVp.p

$$\text{VOLTAGE RATIO} = \frac{4.6\times10^{-3}}{2\times940\times10^{-3}} = \frac{4.6\times10^{-3}}{1880\times10^{-3}} = .002447$$

$dB = 20\ LOG_{10}(.002447) = -52.23dB$
$\%AM = 100 \times (.002447) \approx 0.25\%$

SCOPE DISPLAY OF HALFWAVE ENVELOPE DETECTOR OUTPUT



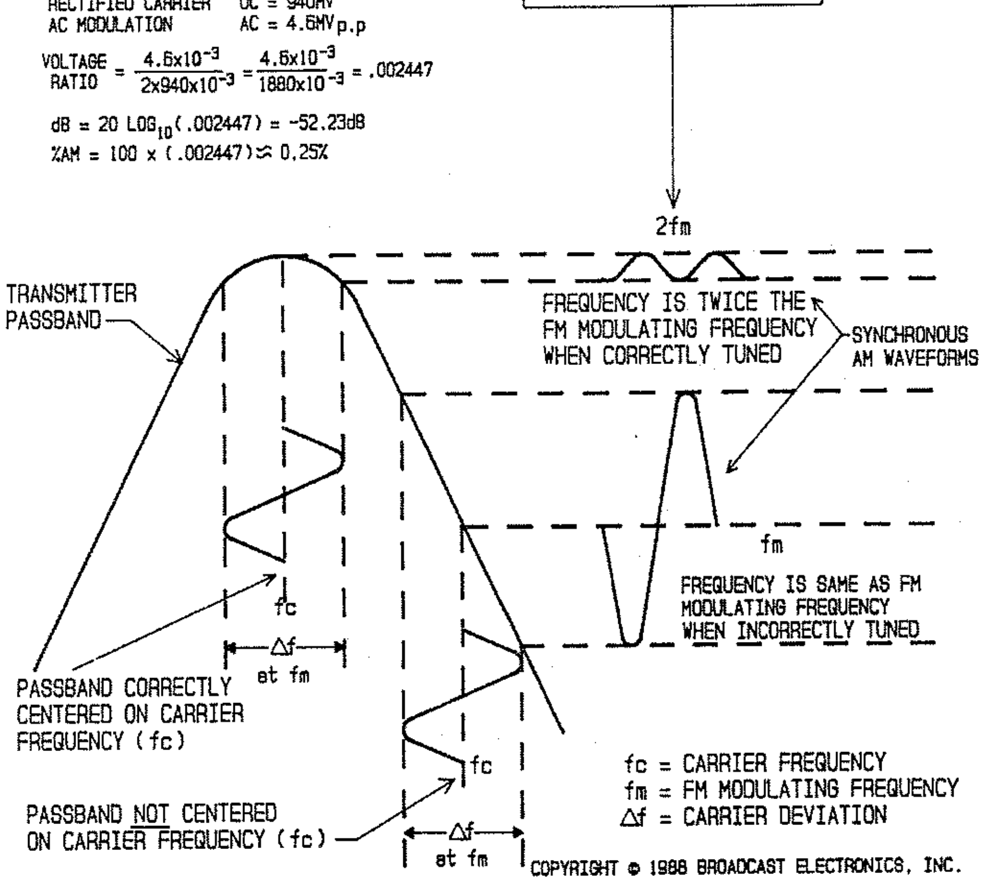
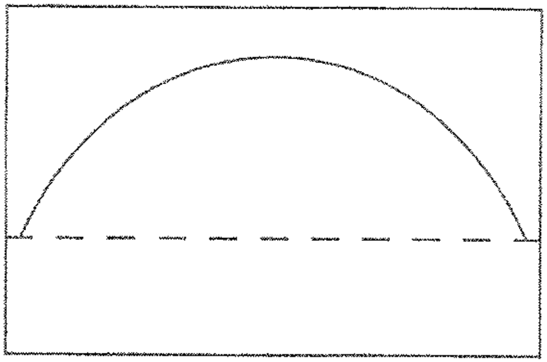
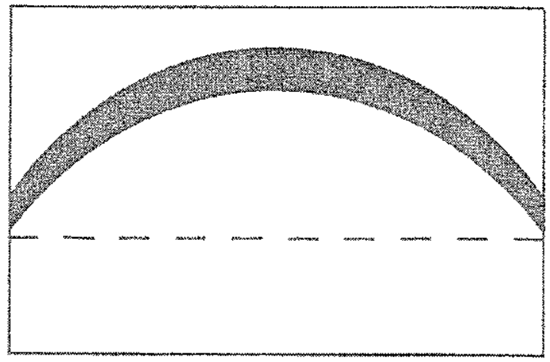




FIGURE 1. SYNCHRONOUS AM WAVEFORMS AND CALCULATIONS

X( HORIZONTAL ) VERSUS Y( VERTICAL )
"PASSBAND" WAVE FORMS SHOWING SYNCHRONOUS AM



400Hz TEST TONE
FIGURE - 2A



WITH TYPICAL PROGRAM MODULATION
FIGURE - 2B



When making the "PASSBAND" measurement on stereo multiplex transmissions, best results will be obtained if the horizontal input of the scope is driven by a sample of the composite baseband being fed to the FM modulator rather than L+R program audio. A sample of the composite baseband being fed to the FM modulator can be conveniently obtained from the front panel composite test jack provided on some FM exciters.

## TEST EQUIPMENT SETUP

Figure-3 illustrates a typical test equipment setup and shows a block diagram of the required test equipment for making synchronous AM waveform measurements. A precision envelope detector with high return loss (low input VSWR) is used so that accurate synchronous AM waveforms can be observed while tuning the FM transmitter. Both the "AM WAVEFORM" and "PASSBAND" measurements can be made depending on whether the scope is in the triggered sweep mode or the X-Y mode. Composite baseband can also be routed into the test setup so that fine tuning can be done with normal programming being broadcast. It should be possible to minimize synchronous AN while maintaining output power and sacrificing little efficiency in a properly designed power amplifier. De-emphasis should NOT be used after the precision envelope detector, since the additional phase shift to the demodulated AM (Y-axis) caused by de-emphasis would not be equal to the phase shift of the composite baseband fed to the X-axis of the display.

BLOCK DIAGRAM FOR SYNCHRONOUS AM MEASUREMENTS

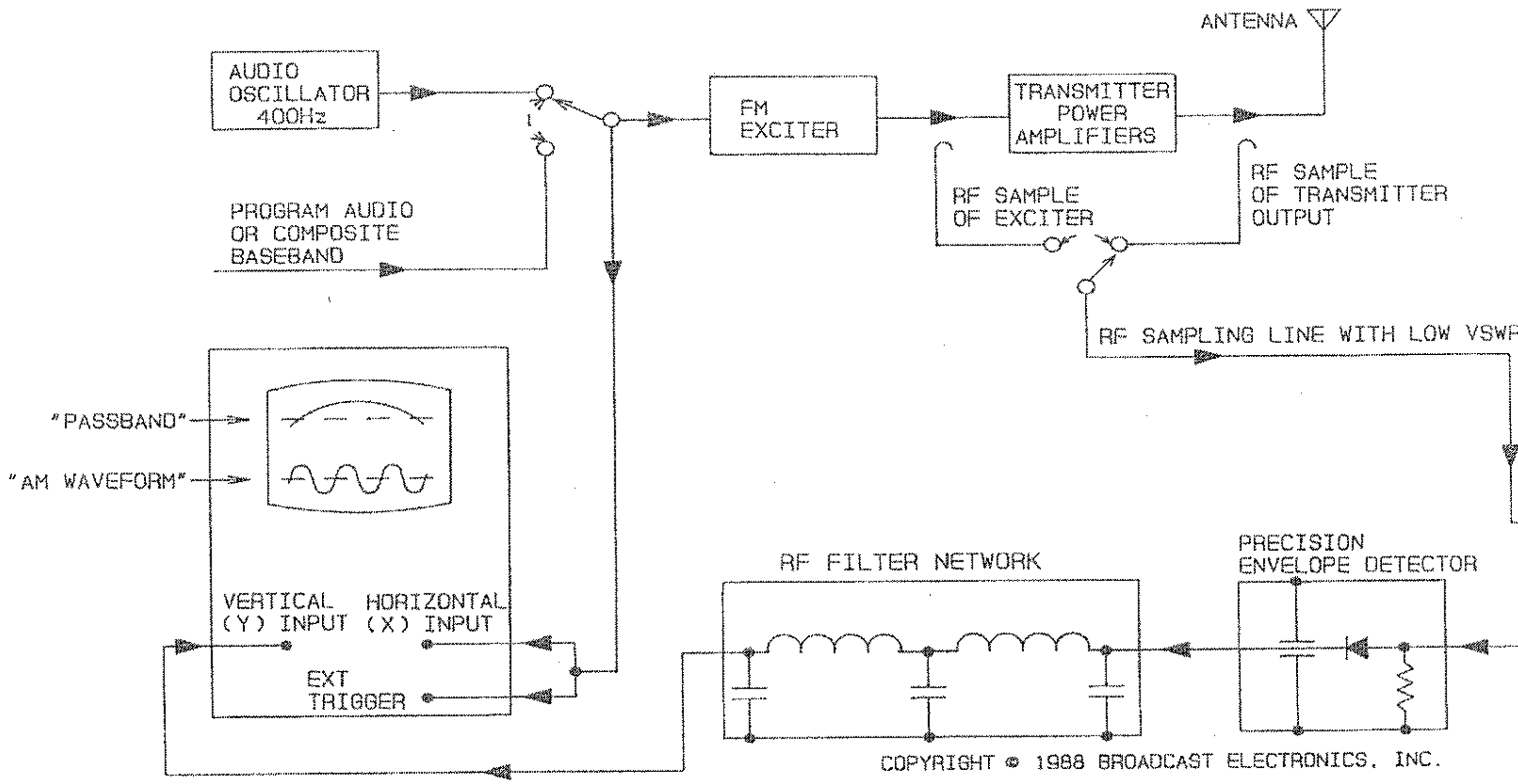



FIGURE 3. BLOCK DIAGRAM FOR SYNCHRONOUS AM MEASUREMENTS

CALCULATING AM NOISE DIRECTLY FROM THE DEMODULATED AM WAVE-FORM

Most FM demodulators cannot be relied upon to make accurate asynchronous AM noise measurements so it is a good idea to cross check the demodulator reading directly against the demodulated output of a precision envelope detector. This can be done by first measuring the DC component of the waveform with a voltmeter or by DC coupling the scope input. The scope is then AC coupled and the input sensitivity is increased until an accurate peak to peak measurement of the AC modulation component can be made. The peak to peak AC voltage is then divided by twice the DC component to obtain the "VOLTAGE RATIO". Twenty times the LOG (base 10) of the "VOLTAGE RATIO" is the actual AM noise level in dB below equivalent 100% AM modulation. Multiplying the voltage ratio by one hundred yields the percent of AM modulation. Figures 1 and 4 illustrate these calculations.

Figure - 4 shows how the percentage of AM modulation can be calculated by directly observing the RF envelope or by the use of the de-modulated waveform from a precision half-wave (peak) envelope detector. Note that the "peak" detected value of the carrier must be doubled to convert it to the "peak-to-peak" value of the carrier. The ratio of the "peak-to-peak" modulation component to the "peak-to-peak" carrier is then used to calculate the percentage of AM modulation as illustrated in Figure - 4.

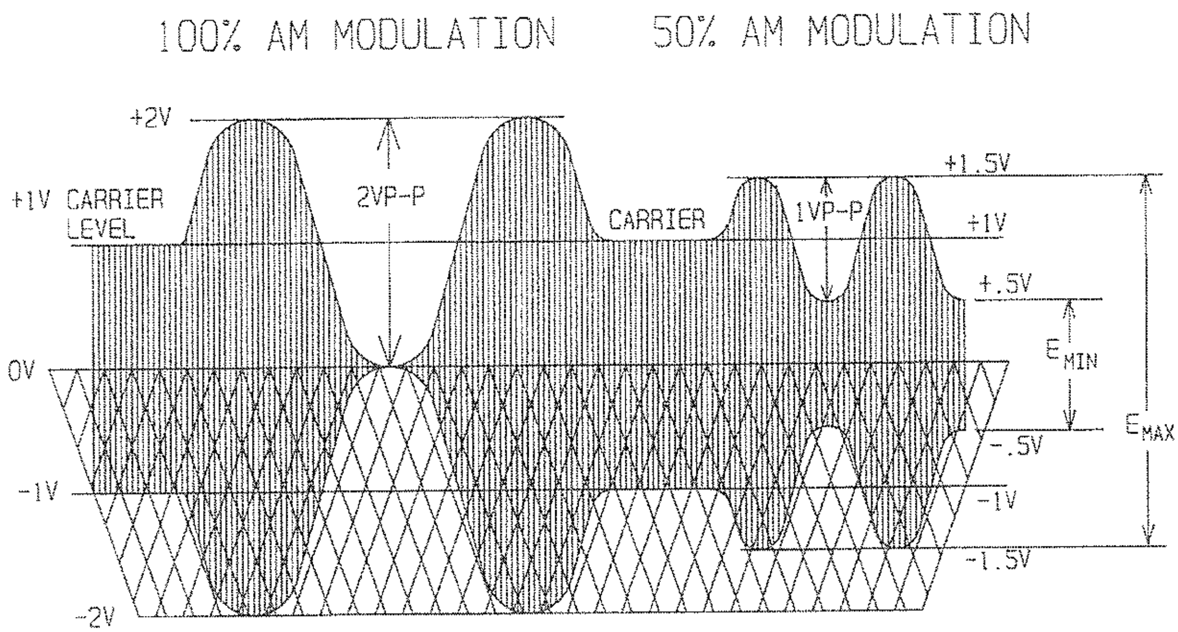
The Need For A Percision Envelope Detector

Care must be taken when making these measurements that the test setup does not introduce synchronous AM and give erroneous readings which would cause the operator to mistune the transmitter to compensate for errors in the measuring equipment.

The input impedance of the envelope detector must provide a nearly perfect match so that there is a very low VSWR on the sampling line. Any significant VSWR on the sampling line will produce synchronous AM at the detector because the position of the voltage peak caused by standing wave moves along this line with FM modulation

Figure - 5 illustrates the effect of the standing wave ratio on the RF voltage presented to the envelope detector. As the sampling line length is increased, the amount of erroneous AM caused by a given standing wave ratio also increases because each additional quarter wavelength causes more movement of the standing wave with FM modulation. Unfortunately, the AM detectors supplied with most modulation monitors do not provide a good enough match to be useful for this measurement. Precision envelope detectors are available from Wide Band Engineering Inc. (model A33) and Hewlett Packard (mode 8471A option 004) that provide a 30 dB return loss (1.06:1 VSWR) to the sampling line when combined with a 10 dB, 50 ohm resistive pad.

# AM MODULATION CALCULATIONS




$$\frac{2VP\text{-}P}{2 \times 1V(\text{CARRIER})} = 1 \times 100\% = 100\%$$

$$\frac{1VP\text{-}P}{2 \times 1V(\text{CARRIER})} = .5 \times 100\% = 50\%$$

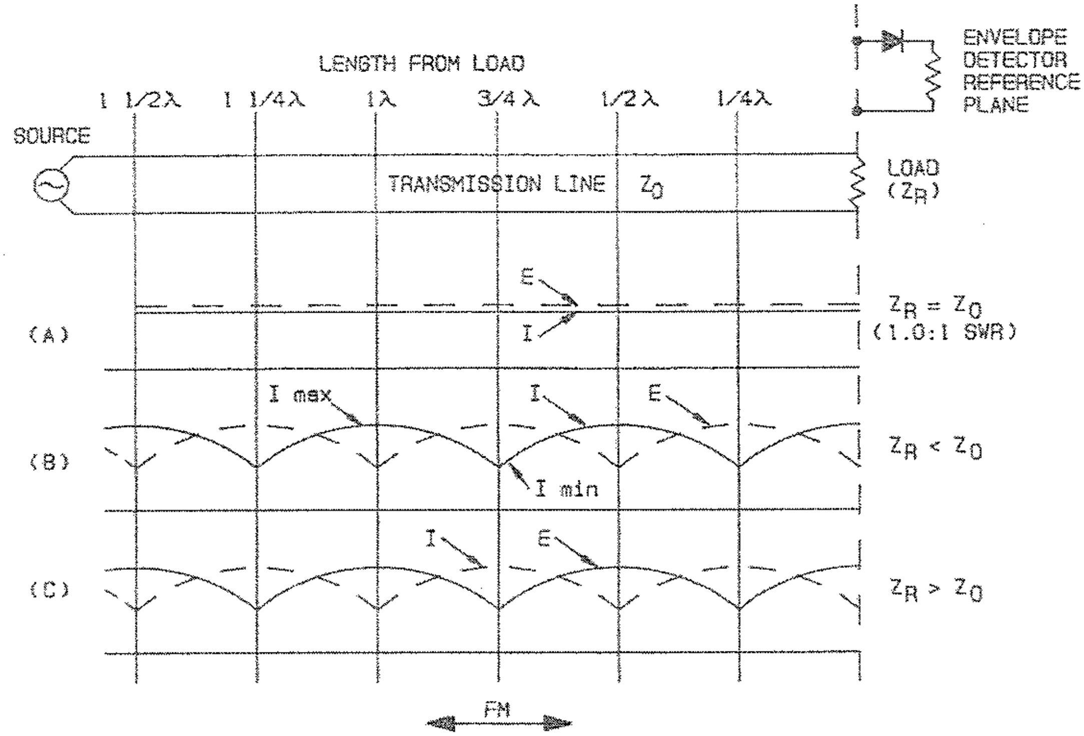
$$AM = \frac{E_{MAX} - E_{MIN}}{E_{MAX} + E_{MIN}} \times 100\%$$

HALF-WAVE ENVELOPE (PEAK) DETECTOR ONLY RESPONDS TO HALF OF THE PEAK TO PEAK CARRIER LEVEL, BUT DOES OUTPUT PEAK TO PEAK MODULATION WAVEFORM. THEREFORE, WHEN CALCULATING THE RATIO OF MODULATION TO CARRIER LEVEL, THE CARRIER LEVEL MUST BE DOUBLED TO CONVERT IT TO THE PEAK TO PEAK VALUE.



FIGURE 4. AM MODULATION CALCULATIONS

EFFECT OF SAMPLING LINE SWR ON SYNCHRONOUS AM MEASUREMENTS




STANDING WAVES ON A TRANSMISSION LINE TERMINATED IN A RESISTIVE LOAD. FREQUENCY MODULATION MOVES STANDING WAVE BACK AND FORTH ALONG LINE CAUSING SYNCHRONOUS AM TO APPEAR AT ENVELOPE DETECTOR.



FIGURE 5. EFFECT OF SAMPLING LINE SWR ON SYNCHRONOUS AM MEASUREMENTS

## Thru-Line Alternative To Percision Envelope Detector

A thru-line type directional coupler normally used to drive the wattmeter movement, has the envelope detector diode built into the sampling element and provides a DC component that the meter movement responds to plus the demodulated AM noise component that meter movement does not respond to. If the thru-line element output is fed to an oscilloscope instead of the wattmeter movement, the synchronous waveform can be accurately measured. This approach eliminates the errors due to VSWR on the sampling line, since the detector is located at the sampling point. Figure - 6 shows how to use a thru-line coupler for making synchronous AM measurements. The manufacturer of the thru-line coupler can supply the special connectors and / or cables to connect its output to the oscilloscope. Care must be taken to avoid hum pick-up from AC ground loops while making these low level measurements.

DETECTOR SETUP FOR: SYNCHRONOUS AM MEASUREMENT

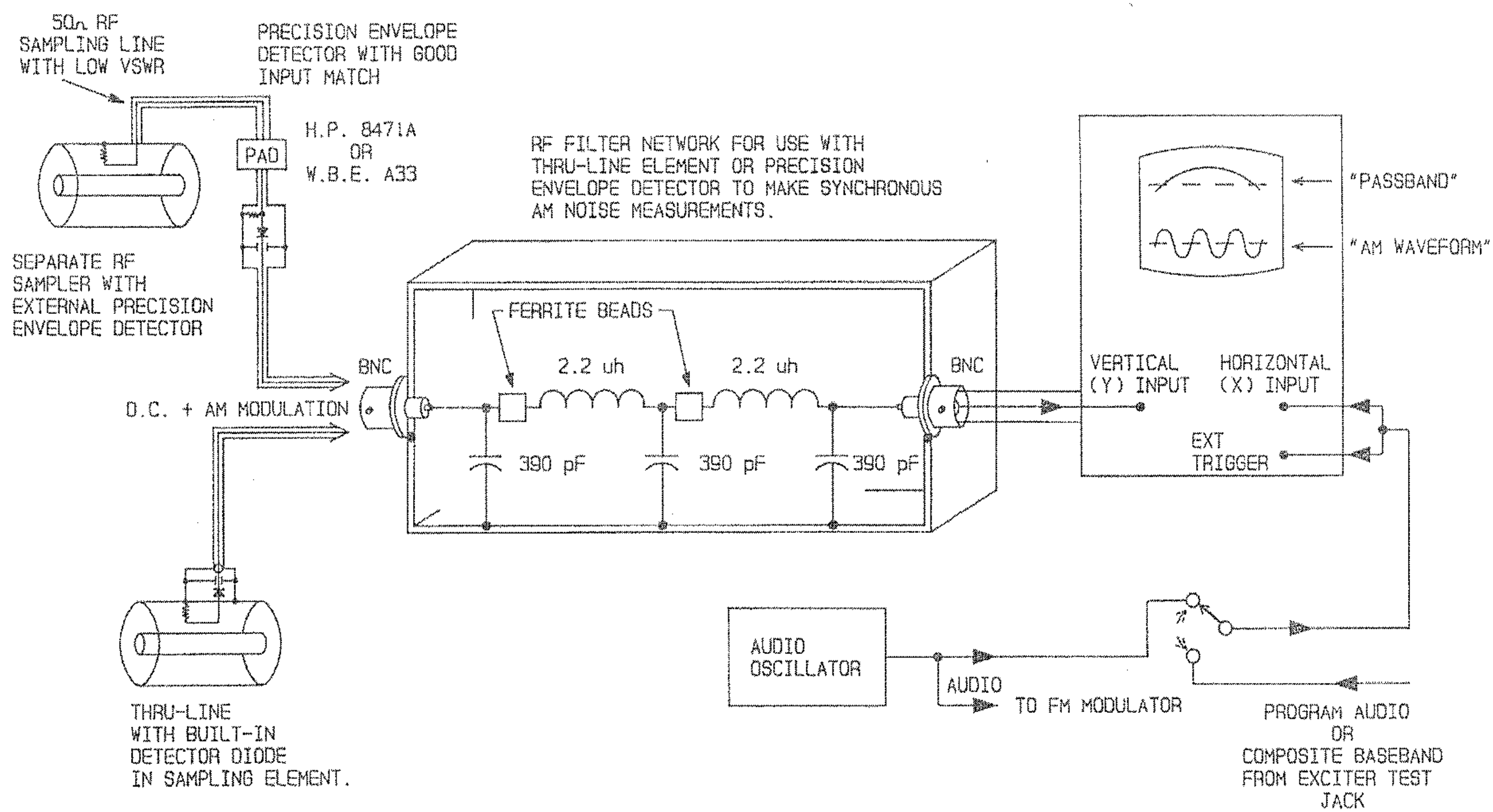





FIGURE 6. DETECTOR SETUP FOR SYNCHRONOUS AM MEASUREMENT

## RF Filter Network

Both the thru-line element detector and the precision envelope detectors have some residual RF on their DC output, so an RF filter network should be placed between the detector and the input the oscilloscope. Figure - 6 shows a suggested configuration for this filter which can be easily constructed in a small shielded enclosure.

## Built-In AM Noise Measurement Capability

Broadcast Electronics has recently developed a built-in precision envelope detector that will be added to the Automatic Power Control (APC) system used in the "A" series of FM broadcast transmitters. A calibrated front panel AM noise test jack will allow observation of the synchronous AM waveform or direct measurement of the synchronous AM noise level on a standard audio voltmeter.

# MINIMUM SYNCHRONOUS AM VERSUS EFFICIENCY

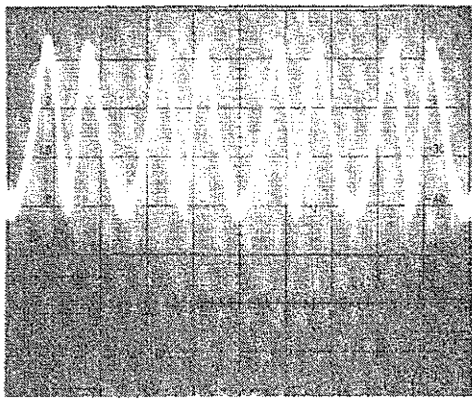
VHF amplifiers often exhibit a somewhat unusual characteristic when tuning for maximum efficiency. The highest efficiency operating point does not exactly coincide with the lowest plate current because the power output continues to rise for a while on the inductive side of resonance coming out of the dip in plate current. If the amplifier is tuned exactly to resonance, the plate load impedance will be purely resistive and the load line will be linear. As the output circuit is tuned to the inductive side of resonance, the plate load impedance becomes complex and the load line becomes elliptic instead of linear since the plate current and plate voltage are no longer in phase. Apparently best efficiency occurs when the phase of the instantaneous plate voltage slightly leads the plate current.

Figures 7A thru 7D show the effect of output loading and efficiency on the shape of the passband. In Figures 7A and 7B, the "WAVEFORM" and "PASSBAND" are asymmetrical even though the minimum synchronous AM point has been reached. The ±75 kHz points have an equal reduction in power output causing minimum synchronous AM, but the shape of the passband between those points is asymmetrical with peak power output occurring below the center (inductive side) of the passband (carrier frequency). Light loading at or beyond peak efficiency operating point causes increasing amounts of this asymmetry and results in increasing amounts of distortion to the FM signal passing through the amplifier. This effect is believed to be caused by the non-linear gain characteristics of the power amplifier tube operating on an elliptic load line.

# EFFECT OF OUTPUT LOADING ON PASSBAND SHAPE

OUTPUT LEVEL "WAVEFORM" VERSUS TIME

"LIGHTLY LOADED"

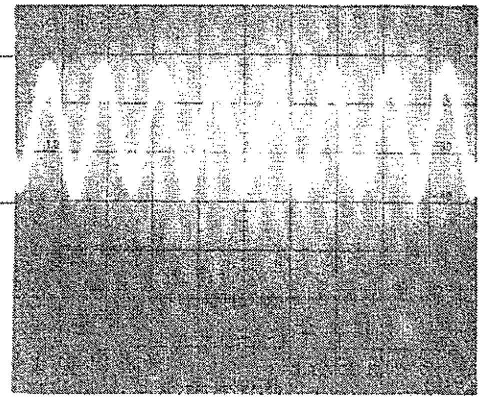


TIME ⟶

FIGURE 7A

1.5% CHANGE IN RF OUTPUT LEVEL (0.5% PER DIV)

"HEAVILY LOADED"

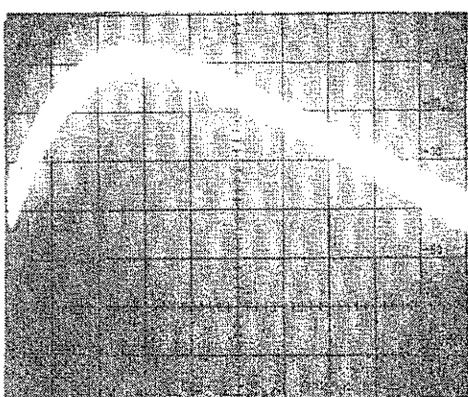


TIME ⟶

FIGURE 7C

OUTPUT LEVEL "PASSBAND" VERSUS FREQUENCY DEVIATION

"LIGHTLY LOADED"



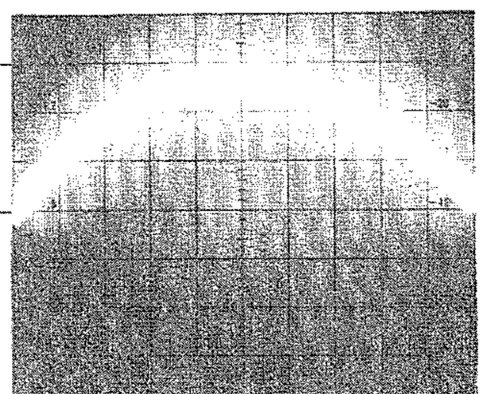
-75HKZ CARRIER FREQUENCY +75KHZ

FIGURE 7B

ASYMMETRICAL PASSBAND CAUSES MORE DISTORTION TO FM SIGNAL

1.5% CHANGE IN RF OUTPUT LEVEL (0.5% PER DIV)

"HEAVILY LOADED"



-75KHZ CARRIER FREQUENCY +75KHZ

FIGURE 7D

SYMMETRICAL PASSBAND CAUSES LESS DISTORTION TO FM SIGNAL



FIGURE 7. EFFECT OF OUTPUT LOADING ON PASSBAND SHAPE

Figures 7C and 7D show nearly perfect symmetry in both the "WAVEFORM" and "PASSBAND" with further reduced amounts of synchronous AM. This is due to heavier loading than required to get peak efficiency. Operating with heavier loading will; reduce the total amount of synchronous AM, improve symmetry of the pass-band, increase the width of the passband, and ultimately reduce the amount of distrotion to the FM signal. The amount of synchronous AM can be minimized at any particualr loading point by tuning the plate, but each change in loading has a new tuning point for minimum synchronous AM. What is the optium point? How much effeciency can be sacrificed?

While increasing amounts of loading will result in the above mentioned benefits, it carries with it the penalty of reduced PA efficiency, so there is a compromise between acceptable synchronous AM and efficiency. A properly designed and neutralized transmitter should be able to achieve acceptable synchronous AM without giving up more than about 3% in PA efficiency.

## CONCLUSIONS

Synchronous AM measurements are an indirect way of evaluating and optimizing FM performance. Even though synchronous AM measurements are a helpful aid to correctly tune an FM transmitter, these measurements tell only (the amplitude response) half of the total story. Transmitter tuning also affects the phase response which in turn affects the relative time delays of the higher order FM sidebands. Even though the amplitude response appears flattened when the grid is heavily driven, the phase response still has a serious effect on the higher order FM sidebands. Fine tuning the input and output for minimum crosstalk into the SCA will allow further optimization of the total amplitude and phase response. Transmitter that utilize wideband solid-state intermediate power amplifiers (IPA) will add less distortion to the FM signal because both the amplitude and phase response will be better than systems utilizing several tuned stages.

## SOURCES OF PERCISION ENVELOPE DETECTORS

Wide Band Engineering Inc.
P.O. Box 21652
1837 East University Drive
Phoenix, AZ 85036
(Model A33)

Hewlett Packard Inc.
1820 Embarcadero Road
Palo Alto, CA 94303-3308
(Model 8471A option 004)

THRULINE® is a registed trademark of:

Bird Electronic Corporation
30303 Aurora Road
Solon, OH 44139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Mr. Mendenhall has designed communications, telemetry, and broadcast equipment for several different manufacturers including several of the leading FM exciters. His practical field experience has involved engineering and operations work for several radio and television stations.

Mr. Mendenhall is presently serving as Vice President of Engineering for Broadcast Electronics, Inc. in Quincy, Illionois.

The author holds three U.S. Patents for electronic designs utilized in broadcast equipment and is a registered professional engineer in the State of Illinois. He has authored numerous technical papers, is an associate member of the AFCCE, and a senior member of the IEEE.

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