AN INTEGRATED AM STEREO DECODER

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ABSTRACT—**This paper describes a monolithic integrated circuit[1] which can be used with a standard Quad Op Amp to form a complete AM Stereo Decoder. The intention of the paper is to show the advantages and trade-offs involved with applying nonsynchronous technology to the unique problems encountered in AM Stereo. The integrated AM Stereo decoder[1] can decode four of the five systems presently under consideration by the FCC.**

I INTRODUCTION

The major problem with broadcasting two independent channels over the AM band is the requirement for compatibility with present day AM radios. This requirement dictates that the information common to both left and right channels (monaural information) must be encoded as amplitude modulation. Somehow the information that is different between the two channels (stereo information) must be encoded in a compatible way. Given a carrier frequency which is amplitude modulated, the only remaining degree of freedom is the phase of the carrier.

There are five proposed ways to encode AM Stereo under consideration at the FCC. At the heart of the controversy is what is the best method to receive an AM Stereo signal. In particular, the question of synchronous detection has become a major area of debate. Strong feelings for or against the detection of AM stations through synchronous detection exist throughout the industry.

The decoder[1] described in this paper is nonsynchronous. Simplicity was the most important reason for the choice. The detail that best illustrates this point is the fact that a nonsynchronous detector is essentially open loop. The possibility of decoding several different AM Stereo systems also had an influence on the decision. The intention of this paper is to show the advantages and trade-offs involved with applying nonsynchronous technology to the unique problems encountered in AM Stereo.

The decoder[1] described in this paper detects pure amplitude modulation for the monaural channel and pure phase modulation for the stereo channel. This is ideal when it comes to detection of the proposed Magnavox AM Stereo system. Due to the way the PM decoder is constructed, it is possible to detect both FM and PM for two different frequency ranges as is proposed by the Belar System. The Motorola system encodes monaural as AM, but the stereo channel is not simple PM. The stereo channel can be realized if the detected phase modulation is distorted by a tangent function and then mulitplied by the detected amplitude modulation. The stereo channel for the Harris system involves distortion by a sine function instead of a tangent. Both the Motorola and Harris system can be approximated by multiplication of the detected phase modulation by the detected amplitude modulation.

II AMPLITUDE MODULATION DETECTION

Compatibility is the starting point to the design of an AM Stereo decoder. In present AM radios, a stronger station sounds louder because a larger input signal appears at the input to a diode decoder. An AM Stereo decoder should resemble a diode in that a larger input signal results in a larger output signal. This is not a problem when it comes to detection of amplitude modulation. Consider an AM Stereo system that is pure AM/PM as is shown in figure 1. Decoded phase modulation is relatively independent of the signal amplitude at the input of the decoder. The left and right output channels are derived from adding and subtracting the monaural channel (AM) from the stereo channel (in this case PM). For maximum separation it is necessary that the amplitude of the detected PM be related to the amplitude of the input signal. This can be accomplished if the AM decoder is a high-quality full wave rectifier. The average output of the AM detector will be proportional to the input signal amplitude and can be used to gain adjust the detected PM.

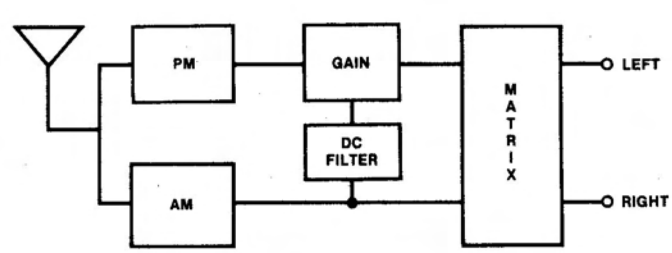

Figure 1. Pure AM/PM Decoder

[1] National Semiconductor LM 1981

A full wave rectifier can be implemented without difficulty using IC technology. The full wave rectifier shown in figure 2 can best be understood by considering what happens if the input signal is zero. Current I_1 and I_2 will be equal as will the voltages of the two nodes fed by the currents. Both currents will be shunted to ground through the two grounded emitter NPN transistors. The bias voltage applied to the base of the double emitter transistor is chosen so that the transistor is barely on. An AC signal applied to the input causes a decrease in one input current relative to the other and the corresponding node will drop in voltage. This turns on one emitter of the dual emitter transistor until the difference current flows through the emitter to the collector. The circuit is completely symmetric and if the two grounded emitter transistors are well matched, the circuit is capable of full wave rectification over a high dynamic range. This circuit also has the advantage of not peak detecting on noise like a diode or peak detector.

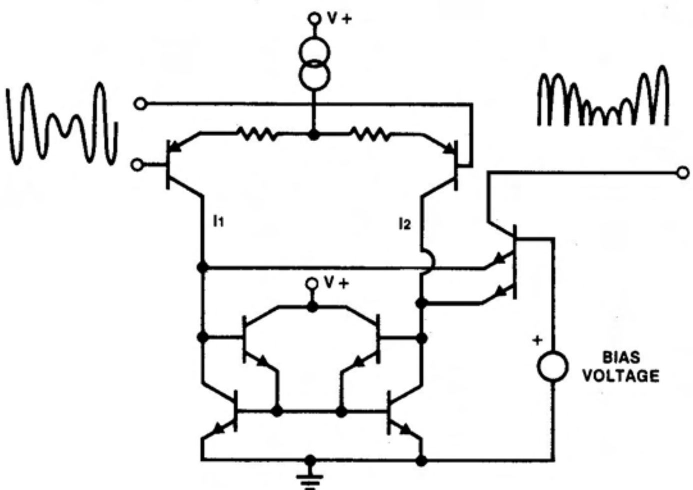

Figure 2. Full Wave Rectifier

III RADIO FREQUENCY RADIATION

Radio frequency radiation is an important consideration when designing an AM Stereo decoder. There are two types of radiation. One type of radiation involves capacitive coupling from the decoder to sensitive circuitry in other parts of the radio. This problem is usually handled by separating the decoded from sensitive circuitry with distance on the PC board or with a grounded shield. The second type of radiation involves magnetic fields. Any signal current generates a magnetic field, and a large percentage of AM radios use antennas that are sensitive to radio frequency magnetic radiation.

The best strategy is to confine all high-frequency processing of signals inside the IC. This of course is not possible since external circuitry is always necessary. Figure 3 shows how an AM Stereo decoder can radiate radio frequency magnetic fields. Think of external circuitry as forming single turn coils with the IC. Radio frequency current flows from the IC, through the external component, back into the IC. The result is a magnetic field produced through the center of the effective coil. Reducing the area of the coil will reduce the amount of magnetic field radiated. Therefore an AM Stereo decoder IC should be pinned out to allow the important external components to be placed as close as possible to the IC. A second important goal is to minimize magnetic radiation due to supply current. This goal puts a constraint on how the stereo channel decoder of an AM Stereo decoder must be designed.

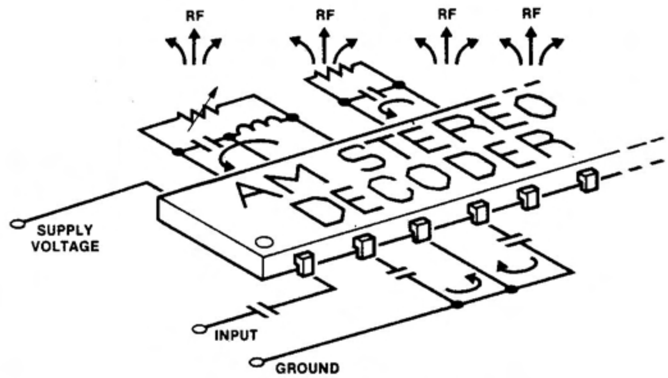

Figure 3. Magnetic Radiation

IV PHASE MODULATION DETECTION

Phase modulation detection can be accomplished by following an FM detector with an integrator. The elegance to this method is that after the signal is detected with a state-of-the-art FM detector, it is both RF filtered and converted to PM by the same integrator.

FM detection involves stripping any amplitude modulation from the signal with a limiter and applying the signal to a frequency-sensitive filter. This filter's output phase is sensitive to input frequency. The FM signal is detected by comparing the output phase of the filter with the phase of the original limited signal.

To minimize RF radiation, a certain philosophy must be applied. If for every transistor that turns on, another transistor turns off, it is possible to keep the supply and ground current constant. The philosophy implies symmetry and for this reason the FM detector and following integrator of the decoder[1] described in this paper were designed to be completely differential.

Figure 4 shows the differential FM detector. The AM is stripped with a limiter which has two outputs. A current from one of the outputs of the limiter drives the frequency-sensitive filter. Ultimately this current makes its way to an internal voltage source (Vref). So an equal and opposite current comes from the other output of the limiter directly to the voltage source. The comparison of phase between the frequency-sensitive filter and limiter output is done with a four quadrant multiplier. The FM detector has two output currents. Resistor R_Q shown in figure 4 determines how sensitive the filter is to frequency. It also defines the maximum linear frequency range of the FM detector. This range is about ± 40 kHz and has little effect on distortion. The usefulness of R_Q is that it can be used to fine-adjust the gain of the overall PM detector for maximum separation.

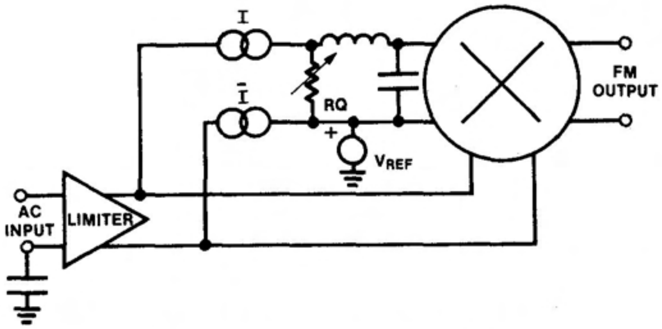

Figure 4. Differential FM Detector

Figure 5 shows the integrator that immediately follows the FM detector. Naturally, this integrator is differential with low noise and distortion. The only thing the integrator lacks is the ability to handle common mode and differential DC current. The outputs of the FM detector have common mode bias current and will have differential current proportional to the mistuning of the radio. Figure 6 shows how some additional circuitry is added to the integrator. Two equal current sources controlled by a common mode feedback loop cancel out the common mode bias current. A simulated inductor is connected across the outputs of the FM detector to handle mistuning. Using a simulated inductor has the advantage of being able to handle relatively high levels of mistuning with low DC offset voltage. An external resistor is also connected across the outputs of the FM detector and has the same function as a shock absorber in an automobile. The correct size of this resistor will cause the PM detector to settle in a minimum amount of time.

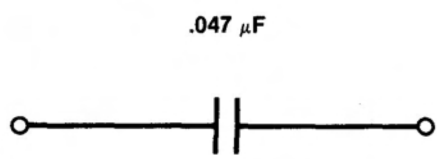

Figure 5. Differential Integrator

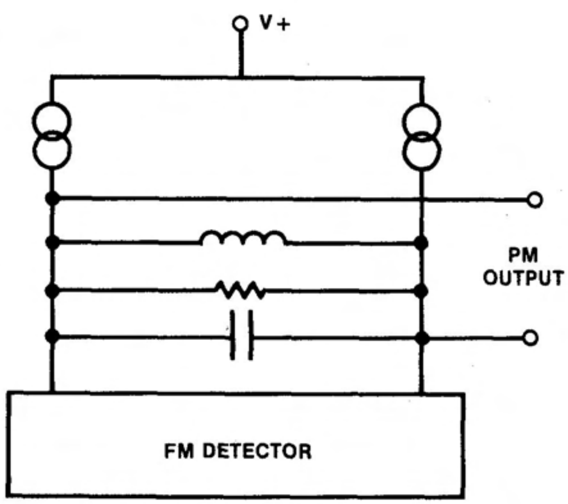

Figure 6. Phase Modulation Detector

The simulated inductor is shown with a little more detail in figure 7. The inductor is somewhat large with an equivalent inductance of 600 Henries. Given an input voltage to transconductance amplifier gm_1, an output current will flow into the .033μf capacitor. For DC conditions the .033μf capacitor has little effect, and as the input voltage to the second transconductance amplifier increases, an output current will result to oppose the input voltage. At high frequencies the .033μf capacitor created phase shift and reduces the amount of output current that opposes the input signal, such that the whole circuit resembles an inductor.

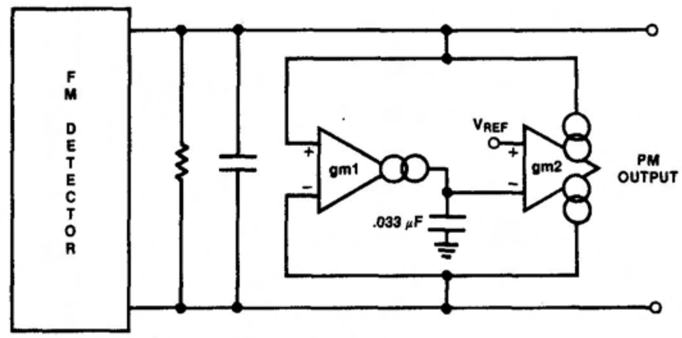

Figure 7. Inductor

The .033μf capacitor defines the size of the inductor. The size of the inductor together with the size of the integration capacitor defines the low frequency pole of the PM detector. The voltage across the .033μf capacitor is directly proportional to the mistuning of the radio. Provided this node is buffered, this voltage could be useful for AFC or center tune meter applications.

The maximum output current of transconductance amplifier gm_2 determines the tune-in range of the PM detector. The amplifier that follows the PM detector has a limited dynamic range. The effect of mistuning the radio will be to cause the output of the PM channel to be up against some maximum limit which will effectively mute the stereo channel. The tune-in range of the PM detector is approximately ±4 kHz.

The tune-in characteristics of the PM detector are defined by this inductor. When the radio is tuned in, it will take a few hundred milliseconds for the .033μf capacitor to adjust to the right voltage. Once this voltage is correct the PM detector will settle out at a rate defined by the low frequency pole of the PM detector. This tune-in wave shape is shown in figure 8.

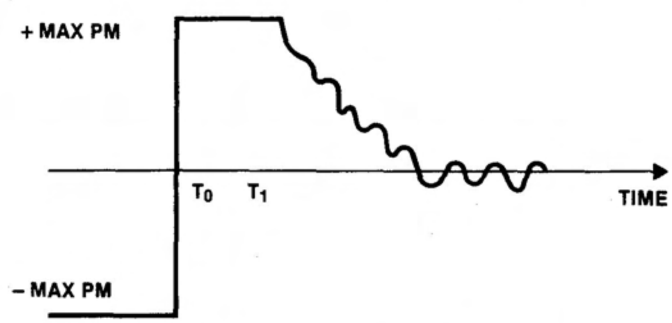

Figure 8. Tune-In Characteristics

Detecting when the PM output is up against a limit is an easy and useful signal to detect. A 90% differential current detector is shown in figure 9. Unless the differential current applied to the inputs exceed 90%, there will be no output current. A differential current excess of 90% means that one of the input currents is less than 10% of the average. For this condition the diode that is connected to that node will turn off and current will flow through the PNP transistor whose emitter is connected to that node. This output can be thought of as an indication of excessive phase modulation.

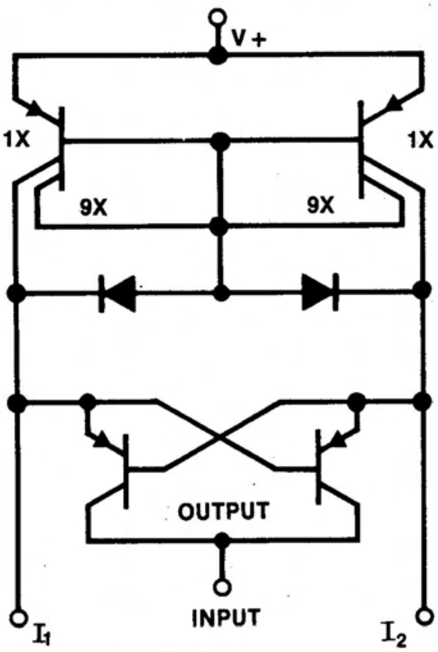

Figure 9. 90% Threshold Detector

V STEREO PILOT TONE DETECTION

There exists a relationship between frequency and time that no technology can overcome. Stated simply, to measure a given frequency with a reasonable accuracy requires at least one cycle. This concept can be extended to understand the relationship of frequency tolerance and the amount of time needed to make the measurement. Measuring one cycle of 455 kHz tells nothing about whether the signal is being amplitude-modulated or phase-modulated. To know modulation at 1 kHz, one cycle of 1kHz is required (1msec). To know modulation at 1 Hz, one second is required. This frequency time limitation has an important effect on AM Stereo.

Ideally it is desirable that AM Stereo resemble FM Stereo. One particular feature of FM Stereo is the ability to detect a stereo station rapidly. A stereo FM station broadcasts a 19 kHz tone to distinguish it from a monaural FM station. Detecting this tone is so fast that an automatic radio can distinguish between stereo and monaural as it sweeps across the FM band. Indication that a station is stereo is almost instantaneous when manually tuning in the radio. Another convenient feature is automatic switching to monaural in the absence of the 19 kHz tone. All of these features are made possible because it does not take much time to accurately detect 19 kHz.

AM Stereo does not have the bandwidth to broadcast a 19 kHz tone. To indicate a stereo station, broadcasting a low frequency pilot tone is the only option. The ability to distinguish an AM Stereo station and automatically switch to stereo may be very important. This feature would prevent AM stations that inadvertently have phase modulation from creating problems. So the ability to accurately detect the pilot tone is important. This means detection time will be slow.

Slow detection of a stereo station is definitely going to distinguish AM Stereo from FM stereo. This fact will be particularly obvious when manually tuning into an AM Stereo station. From the listening standpoint, stereo reception is perceived to be instantaneous. This is because it takes a while to fine-tune a radio and the stereo channel decoder is capable of following the hand as it fine-tunes. It is relatively simple for a hand to generate low frequency phase modulation which the decoder has no difficulty in accurately decoding. Given that the pilot tone will also be low frequency, this makes accurate detection of the pilot tone more interesting.

The five different proposed AM Stereo systems have five different ways to encode this pilot tone. There are of course five different frequencies and relative amplitudes. The systems with the higher frequencies also have low amplitudes so they don't necessarily have the advantage. It is doubtful whether there is a universal way to decode all five pilot tones. For this reason the AM Stereo decoder[1] described in this paper relies on an external pilot tone decoder.

VI STEREO RECEPTION

The need for compatibility between a monaural and stereo AM signal may have serious consequences concerning the reception of AM Stereo. Consider a constraint that the AM station must be able to amplitude-modulate the carrier up 125%, and down to nearly nothing. While the amplitude is at its minimum, it must be possible to independently detect the stereo channel. Figure 10 shows this case where the stereo channel is encoded as pure phase modulation. Theoretically the decoder[1] can detect the FM information of the carrier down to the point where the signal will completely disappear. At this point the FM detector should produce no output and the following integrator will sample and hold during that period of time. It is fair to say that the stereo channel detector cannot detect a signal while the input signal is zero and therefore it must estimate during that period of time.

Although it is possible to generate in the laboratory the condition shown in figure 10, this situation rarely happens. All received radio signals have background noice or interference. It is fair to say that the stereo channel detector cannot detect the stereo channel during periods of time when the AM Stereo signal is buried in background noise or interference. It is fair to assume that during those periods of time the stereo channel detector will detect the background noise or interference as though it is the intended stereo signal.

The proposed Motorola, Magnavox, and Belar AM Stereo systems all propose amplitude modulation of the carrier by the monaural channel independent of the stereo channel. For adverse reception conditions where the background interference

In conclusion, the application of nonsynchronous technology to the unique problems of AM Stereo has been described. Two particular problems have been encountered that it is not obvious any technology can overcome. The first problem involves the requirement of time to detect a low frequency pilot tone. The second problem involves the inability to detect a signal during periods of time when the signal is buried in background noise or interference. It is not unreasonable to assume that these two problems will be solved in a satisfactory way. There does not appear to be any serious problems limiting the performance of an AM Stereo decoder. Future improvement of an Am Stereo decoder will be heaviliy affected by improved AM Stereo signal generators and better definition of decoder requirements in the future.

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