35

Subsidiary Communications and Stereophonic Broadcasting

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SUBSIDIARY COMMUNICATIONS AUTHORIZATION (SCA) FOR FM BROADCAST STATIONS

Federal Communications Commission Rules and Regulations provide for the utilization by FM broadcast stations of subcarriers transmitted along with the main channel programming.

This mode of operation, licensed under FCC Subsidiary Communications Authorization (SCA), can accrue advantages of financial or special service nature to commercial and noncommercial FM broadcasters.

The grant of the SCA service is conditioned on the rendering of services satisfying the basic requirements that the program transmissions shall be of a broadcast nature of interest primarily to limited segments of the public wishing to subscribe thereto, or that the signals transmitted relate directly to the operation of FM broadcast stations.

The Commission specifically states that those programs of a broadcast nature may be background music, storecasting, detailed weather forecasting, special time signals, or other material of a broadcast nature expressly designed and intended for business, professional, educational, trade, labor, agricultural, or other groups engaged in any lawful activity. This is an extremely broad area of acceptability; however, in practice by far the greatest utilization of SCA has been in the background music and storecasting categories since revenue to the FM broadcaster results from these commercial operations. These revenues have in many instances represented a major part of the income to the FM broadcaster. Other programming in current use relates to the dissemination of agricultural market information and, recently, the broadcast of "radio talking book" material to the visually handicapped. A number of educational institutions use their subchannels for "in-home" teaching purposes. The Commission has recently expanded the permissible transmission to include slow-scan TV, teletype, facsimile, and other nonaural electronic services.

Typical examples of SCA use in the category of signal transmission directly related to the operation of FM broadcast stations include coded telemetry data for FM broadcast remote control operations and the relaying of sports and other specialized types of programming on a regional network basis.

The current FCC rules pertaining to SCA engineering standards define very few parameters. The standards state only that the subchannel shall be frequency modulated, define the carrier frequency ranges for mono or stereo operation, stipulate carrier injection levels for each main channel mode, and specify permissible crosstalk levels from the SCA channel into the main channel. No standards for the performance of the subchannel itself are established. Audio frequency response, total harmonic distortion, preemphasis characteristics, signal-to-noise ratios, or crosstalk from the main channel programming into the subchannel are not specified. Thus, the Commission standards provide no indication of actual performance to be anticipated from the subchannel. It is anticipated that the FCC proposed rule-making mentioned above will include specific parameters as minimum standards for SCA transmission performance.

In actuality, a subcarrier multiplex channel is capable of surprisingly high-quality, low-noise operation.

It is the objective of this material to define these capabilities with direction as to the proper use and adjustment of the system elements to provide optimum performance. Each of the system elements is discussed in detail.

The heart of the system is, of course, the basic subchannel carrier generating and modulation processing equipment. There are a number of SCA generators available on the market, and the Commission permits the use of SCA generators of any manufacture with any FM broadcast transmitter/exciter which has been type-accepted for SCA operation. In other words, type acceptance of SCA generators is not required.

Let us first consider the effect of adding a new channel, the 67-kHz frequency-modulated subcarrier to an existing stereophonic FM broadcast system. Assuming that the 67-kHz subcarrier will be deviated ±6 kHz (61 to 73 kHz), we have present in the complete modulation spectrum this energy plus the main channel mono audio portion, essentially 30-15,000 Hz; the stereo pilot carrier at 19,000 Hz; and the stereo suppressed-carrier double sideband AM information, which when fully modulated occupies the region from 23 to 53 kHz, centered around the 38 kHz suppressed carrier. This information spectrum is shown in Fig. 1.

Several points become apparent. First, the addition of the SCA fully modulated subcarrier indicates the need for flat frequency response of the transmission system to 73 kHz rather than to the 53 kHz limit for stereo operation.

If any nonlinearities exist in the transmission system, troubles develop rather rapidly. These can result from improper neutralization or loading of any of the RF stages in the transmitter itself, high VSWR on the transmission line or narrow bandwidth characteristics in the antenna system.

Acceptable bandwidths are attainable with present day FM transmitters, but it is essential that the transmission system be routinely checked for maintenance of optimum bandwidth conditions. A spectrum analyzer, where available, provides the best means of detecting overall performance; however, FCC rules for type approval of stereo and SCA modulation monitors include the capability of measuring response within 1 dB accuracy from 50 Hz to 75 kHz. As a preliminary check, the overall response of the transmission system should be measured, using a spectrum analyzer or a type approved modulation monitor in conjunction with a signal generator covering the 50 to 75,000 Hz range. If nonlinear response is detected at the transmitter output, the source of the defect can be isolated by temporarily connecting the monitor feed to preceding RF stages, or the exciter output itself. This procedure is also helpful in isolating crosstalk problems, particularly where neutralized tetrode IPA or PA stages follow the exciter. *Any* nonlinearities in the transmission system will seriously affect both main to SCA and SCA to main channel crosstalk characteristics. Transmission line VSWR must be maintained at as reasonably low values as practical (typically 1.1 to 1) to assure optimum performance. Present day transmitting antenna designs usually provide adequate bandwidths. If, however, antenna problems appear which result in increased VSWR readings, increased crosstalk between the stereo and SCA information will almost certainly occur.

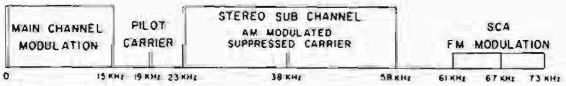

Fig. 1. Complete FM Spectrum of a stereo and SCA transmission.

A great deal of comment is heard relative to "birdies" and "whistles" which suddenly appear when a subchannel is added to a stereophonic operation. This condition, although potentially created in certain receiver designs, details of which will be given later, may also be generated in the transmitter part of the system. When present in the transmitter, they may be detected by a type-approved modulation monitor as described above and *must* be corrected if a clean overall system is to result.

The addition of the 67-kHz subcarrier to an existing stereo system presents the possibility of generated beat frequencies of 9 kHz and/or 10 kHz; or of random "swishy" by-products, all of which are in the audible range. The source of the 10-kHz signal is from the third harmonic of the 19-kHz pilot-carrier signal which falls at 57 kHz, 10 kHz below the 67-kHz subcarrier. Some earlier stereo generator designs also produced second harmonic content from the 38 kHz suppressed carrier switching circuitry. This second harmonic falls at 76 kHz and produces a 9 kHz product when intermixed with the 67-kHz subcarrier. The 9- or 10-kHz products appear as relatively clean "whistles" when no modulation is present. When the subchannel is modulated (deviated ±6 kHz) the products appear as "swishes" as the 67 kHz modulation sidebands are generated and beat with the pilot carrier third harmonic and/or the 38 kHz second harmonic.

If either 57 kHz or 76 kHz signals or any other spurious signals appear in the transmitter output, they must be eliminated. Suggested steps for optimum operation include:

1. Insure that the 19-kHz pilot carrier is free of third-harmonic content and does not exceed 10 percent injection level.

2. 38-kHz carrier suppression must be at least 50 dB below a 100 percent modulation reference level.

3. SCA carrier injection should be maintained at a 9½-10 percent level.

4. A sharp 5-kHz low-pass filter (optional with some SCA generators) should be inserted in the SCA program output circuitry. This prevents the appearance of harmonics of nonsinusoidal SCA program material above 5 kHz in the SCA generator output which can produce excessive SCA sidebands which would extend below the lower bandwidth limit assigned to the subchannel

information and generate interference with the stereo information channel which has a 53-kHz upper limit.

5. The left- and right-channel audio inputs of the stereo generator should incorporate 15-kHz low-pass filters to insure that sideband signals of the stereo transmission do not extend beyond the 23 to 53 kHz (38, ±15, kHz) limits assigned to it.

6. The SCA generator should include a 67-kHz bandpass filter in its output to insure that (a) the lower sidebands do not interfere with the 53-kHz upper stereo information frequency limit and (b) the upper sideband does not extend beyond the 75-kHz upper limit established by FCC rules.

7. Although modern FM transmitter and stereo/SCA generator design is capable of accommodating ±6 kHz deviation of the subchannel carrier, it is recognized that many broadcast systems utilize equipments of various ages and manufacturing designs. In a number of instances, it is worthwhile, if satisfactory performance cannot be realized with ±6 kHz deviation of the subcarrier, to consider reduction in deviation. Reducing the deviation to ±4 kHz results in a signal-to-noise increase of 4 dB in the subchannel transmission.

If the above precautions are taken, at worst, minimal SCA interference will be transmitted. In most cases, a spectral display will prove that SCA interference is not being transmitted.

The station engaged in SCA and stereo transmission must, however, insure that it is transmitting a clean signal and this can be verified by a properly operating monitor or spectrum analyzer. This can be done by removing all stereo modulation and measuring the SCA interference (crosstalk) into the main (L + R) channel and the stereo sub (L-R) channel. Any crosstalk or interference must be down at least 60 dB from 100 percent modulation into the main and stereo subchannels. If these parameters are met, the station knows that at least it is not contributing intermodulation products or SCA interference.

Stations transmitting SCA have one additional problem, that of the stereo information getting into the SCA channel. This crosstalk interference is of great concern to the background-music operator and other users of the SCA channel. Clean SCA with stereo transmission requires optimum performance of the transmitter and associated equipment and in fact requires more demanding system and equipment linearity than for a stereo-only transmission.

In a stereo transmission, equal levels of signals are transmitted on the left and right channel. When SCA transmission is added, 90 percent of the total information is transmitted on the main and stereo channel with only 10 percent of the baseband modulation used for the SCA channel. Thus, the main and stereo channel is nine times greater in amplitude, requiring high transfer-characteristic linearity.

The 35-dB crosstalk (separation) between left and right audio channels of the stereo transmission is indeed excellent and hard to achieve at all frequencies, but this degree of crosstalk would be unusable for SCA programming. Poor separation between the main and stereo channels is more attributable to phase error, time delay or amplitude error than nonlinear transfer characteristics.

In an SCA transmission, crosstalk can originate due to nonlinearities in the FM exciter, transmitter, transmitting, and receiving antennas or multipath reception effects of the main channel section of the SCA receiver.

To preserve reasonably good phase linearity in an FM exciter, the actual cutoff frequency of the 53-kHz low-pass filter following the modulator in stereo generators may be 60 kHz or higher, and stereo sidebands can extend well into the SCA channel. Thus, linear crosstalk from the stereo subchannel (23-53 kHz) can be transmitted into the SCA channel. This is characterized as a "monkey-chatter." This is not due to nonlinearities but is created by upper stereo AM sidebands exceeding the 53-kHz design limit and appearing in the 67-kHz SCA channel. Nonsinusoidal stereo program material in the 8-15 kHz region with high harmonic content can also produce AM sidebands of the stereo information which extend into the SCA channel. These amplitude-modulated signals will ride up and down the response curve of the SCA band-pass filter, creating a form of phase modulation which will be detected as noise in the recovered SCA audio. This type of transmitted interference is easily corrected by inserting sharp 15-kHz low-pass filters in the left and right audio channels of the stereo generator, preventing any stereo upper sideband components from exceeding 53 kHz.

The absence or malfunction of 15-kHz low-pass filters may be detected by fluctuation of the pilot injection level reading on the stereo monitor. This fluctuation is produced by harmonics of the program audio frequencies falling into the pass band of a highly selective 19-kHz filter used in the pilot injection level measuring circuitry of the monitor.

The above sources of crosstalk relate to direct, or linear, operating conditions. The major, and most serious, cause of main or stereo crosstalk into the SCA channel is caused by nonlinear transfer characteristics (intermodulation distortion) which can originate in the exciter, power amplifier, transmitting and receiving antennas, or in the main channel portion of an SCA receiver.

An understanding of events occurring during the FM modulation process is necessary to better comprehend the crosstalk problem. The FM process is complex. An FM transmitter monaurally modulated 100 percent with a 600-Hz audio signal will create several hundred new carriers or sidebands above and below the center frequency. The strength of each of these carriers can be computed mathematically using Bessel functions. When a 67-kHz signal is added to the modulation process, two new carriers removed 67 kHz from the center frequency are produced. When these carriers are frequency modulated, additional new sidebands appear above and below these respective carriers. Any disturbance of these carriers or their sidebands will create intermodulation or crosstalk.

Most present-day FM exciters use the direct FM system operating at one-half the carrier frequency or at carrier frequency. The linearity of these modulated oscillators must be near perfect. The bandwidth of the RF amplifiers in the exciter following the modulated oscillator must be adequate to allow all of the upper and lower sidebands produced by the FM process to pass without deterioration. The correct phase relationship between the sidebands must be preserved. The shift in phase as the FM frequency changes must be a linear function. If the slightest regeneration is present, the phase shift will be more rapid above the center frequency than it is below, or vice versa, and intermodulation or crosstalk will occur. In effect, regeneration can be one of the most serious sources of crosstalk in the exciter. The pass band following the modulator must be at least 1 MHz wide for good linearity. The typical exciter illustrated in Fig. 2 is designed with all of these parameters in mind and with particular attention to proper filtering. The 15-kHz low-pass filters are used in the left and right audio input channels of the stereo generator. A 53-kHz low-pass filter is inserted in the stereo generator output. A 5-kHz low-pass audio input and a 67-kHz bandpass output filter are used in conjunction with the SCA generator.

Proper coupling must be maintained between the exciter and the subsequent RF amplifier stage. The stage being driven must present a non-reactive load to the exciter. Any reactance existing between the exciter and power amplifier will produce phase shift due to nonlinear response to signals appearing above and below the center frequency. Thus, the sidebands are altered from their original relationship to each other and crosstalk is produced. Improper neutralization of PA stages will cause regeneration and crosstalk.

A portion of the transmission system that is often overlooked is the transmitting antenna. Again, the transmitting antenna and transmission line must present to the transmitter a purely resistive load. A correctly tuned antenna system is capable of producing a VSWR close to unity, generally 1.1:1.

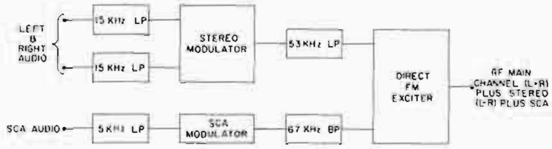

Fig. 2. Block diagram of a typical FM exciter.

A further test of good antenna performance is to sweep it out and measure the change in reactance over a minimum of 1 MHz from the center operating frequency. A curve, representing the change in reactance, should be symmetrical on either side of the operating frequency if satisfactory multiplex operation is to result.

It is often taken for granted that the antenna can cause no problem. The antenna should be measured and adjusted, especially if it has been in operation for a number of years and the SCA multiplex operation is now being initiated.

Some of the major causes of crosstalk in the transmitter end of SCA multiplexing have been outlined. Any station that follows good engineering procedures when converting to SCA operation will be rewarded with excellent results.

It was stated earlier that FCC engineering standards do not include performance characteristics for the SCA channel. As a guideline to what the anticipated performance of a subchannel might be, the following is typical of present-day SCA transmission with stereophonic main channel operation.

SCA subcarrier	67 kHz
SCA frequency response	30-5,000 Hz, ±1.5 dB
SCA total harmonic distortion	1.5%
Signal-to-noise (essentially crosstalk, main to SCA)	—55dB
Crosstalk, SCA to main	—60dB

The optimum performance attainable with SCA operation in conjunction with monophonic main channel programming is most impressive.

A series of field tests was conducted in the late 1960s utilizing the facilities of KFAB-FM, Omaha, Nebraska. A subchannel frequency of 58 kHz was used and a maximum deviation of ±12 kHz was employed. The modulation of the main carrier by the subcarrier (injection) was 20 percent. The main channel had a measured frequency response which was flat, within 1.2 dB, from 50 to 15,000 Hz. During all subchannel measurements, the monophonic main channel was programmed with high quality recorded music. The 75 μ sec. pre-emphasis was used in both the main channel and subcarrier channel. Measurements taken with type-approved monitoring equipment at the transmitter, were:

Crosstalk (subchannel into main)	Greater than —70 dB
Subchannel FM signal-to-noise (no main channel mod.)	—70 dB

SCA channel total harmonic distortion

Frequency in Hz	% Distortion
50	.55
100	.46
400	.45
1,000	.40
2,500	.80
5,000	.68
7,500	.65
10,000	.60
15,000	1.20

SCA frequency response (200 Hz ref.)

Frequency in Hz	Response (departure from 75-μsec. curve)
50	0.0 dB
100	0.0
200	0.0
1,000	+0.1
3,800	0.0
5,000	—0.6
10,000	—2.0
15,000	—0.7

Measurements were taken on a standard SCA receiver modified for ±12 kHz deviation, 15-kHz frequency response and 75 μ sec. de-emphasis. The receiver was located approximately 12 miles from the transmitter site, and used a simple indoor dipole antenna, oriented for maximum signal. The antenna input signal was approximately 1 mv. The results were as follows:

Crosstalk (subchannel into main)	greater than —70 dB
Crosstalk (main into SCA)	During a 15-minute test period, the highest crosstalk measured was -55 dB with total main channel modulation not exceeding 100%
SCA signal-to-noise, plus crosstalk	— 49 dB (using 400 Hz @ 100% modulation as reference)
SCA signal-to-noise (no main channel modulation)	—57 dB

While the applications for an SCA channel capable of this high degree of performance are extremely limited, the test data is of interest since it does demonstrate the subchannel capability, as well as the relative values of degradation contributed by the receiving equipment portion of the complete transmission system.

Generally, the introduction of SCA multiplex operation as an adjunct to an existing FM broadcast station operation suddenly involves the station engineering personnel with a "whole new ball game"—the SCA receiver. Frequently, the SCA operation involves the leasing of the facility by a third party interested primarily in the results produced at the receiving location, for which he assesses a fee. The SCA receivers used by the subchannel lessee are frequently selected, purchased, installed, and serviced by his own separate organization, completely unrelated to the FM station licensee.

Herein lies the potential for unbelievable misunderstandings! Are problems which may occur in the overall system produced by the transmitting end, or by the receiving end? Two points become of extreme importance to the station engineer. First, be certain the transmitting end is clean and technically sound; and second, and equally important, understand the technical aspects of the receiving process, particularly as it relates to the possibility of "crosstalk" problems, which are the most frequent complaint and which may be produced by effects in the receiving process with which previously you have not had to be concerned.

The receiving antenna, multipath effects, and the SCA receiver itself can generate nonlinear crosstalk. The SCA receiving antenna, even for line-of-sight situations, should be as highly-directional as possible and "cut-to-frequency." The antenna directivity characteristic is essential to insure maximum direct path signal intensity and to minimize reception of secondary signals reflected from structures in metropolitan areas or from terrain irregularities in mountainous environments. Reflected signals alter the phase relationship of the transmitted sidebands of a carrier produced by a transmitter with good linearity. Bear in mind that the programming to be recovered by the SCA receiver is carried on a subchannel with one-tenth of the signal strength of your transmitted signal.

The generally accepted standard SCA receiving antenna is of either 3- or 5-element, single-bay, Yagi configuration; occasionally supplemented by an additional bay for "fringe-area" installations. Coaxial transmission line, of 50- or 75-ohm surge impedance, is essential to minimize secondary feedline pick-up.

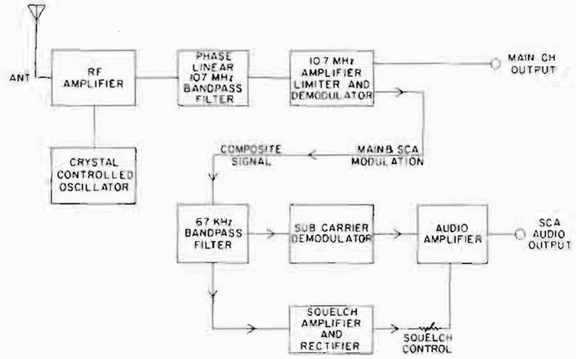

Fig. 3. Block diagram of a typical SCA receiver.

The block diagram of a typical SCA receiver is shown in Fig. 3.

The SCA receiver must amplify the RF carrier and detect it without seriously disturbing the original signal and its sideband information. To do this, most of the signal amplification and selectivity is achieved in the main IF amplifier section of the SCA receiver. Fortunately, present-day detectors are of sufficient bandwidth with good linearity and contribute very little to crosstalk. The problem has resolved itself to the band-pass IF filter or filters which must pass the modulated signal with sidebands undisturbed.

The requirement for an IF band-pass filter that will not create intermodulation products and will maintain good selectivity is costly and hard to achieve. The bandwidth must be adequate, and the phase linearity must be such that minimum disturbance of the upper and lower sidebands will occur. The bandwidth must be adequate to minimize the unwanted conversion of the FM signal to AM in the IF system which would produce a side product of intermodulation into the SCA carrier. Even though the signal is hard-limited, the intermodulation product will show up as phase shift, and will be detected by the FM detector and end up as crosstalk in the SCA audio.

SCA channel total harmonic distortion

Frequency in Hz	% Distortion
50	.50
100	.55
400	.60
1,000	.60
2,500	.60
5,000	.60
7,500	.90
10,000	.80
15,000	1.30

SCA channel frequency response (200 Hz ref.)

Frequency in Hz	Response (departure from 75-μsec. curve)
50	−0.2 dB
100	0.0
200	0.0
1,000	−0.4
3,800	−2.0
5,000	−2.6
10,000	−1.2
15,000	+0.4

The 67-kHz band-pass filter must have adequate selectivity to prevent linear crosstalk as previously described.

If intermodulation occurs anywhere in the transmission or receiver system, crosstalk results and there is no way to remove the main or stereo channel from the SCA channel.

A serious problem that occurred in early solid state receivers was front-end overload. Receivers using bipolar devices in the RF amplifier were very susceptible to this type of interference. This phenomenon was caused by strong RF signals, many channels removed from the desired signal, driving the base-emitter junction of the RF amplifier into conduction. Thus, the RF amplifier became an excellent mixer rather than an amplifier. This was evidenced by an apparent lack of receiver sensitivity and high noise. Removing the antenna, inserting pads, or short circuiting the antenna input restored the receiver to normal operation. The more sensitive the receiver, the greater the susceptibility to this type of overload. Forward AGC reduced the gain but this lowered the input impedance of the device drastically, which in turn reduced front-end selectivity, causing additional problems.

The advent of the JFET and especially the MOSFET transistor has greatly enhanced the overload characteristics of present-day receivers. MOSFETs, when used with good preselection, can operate with input signals up to 0.3 volts or greater with very low intermodulation products, thus fully utilizing the selectivity characteristics of the IF system.

Another source of intermodulation, or crosstalk, in receivers can occur in the IF amplifier limiters. Symmetrical limiters preserve the zero time axis crossing of the IF signal while providing hard amplitude limiting. This results in practically zero amplitude-to-phase modulation conversion and no intermodulation products.

The SCA receiver shown in Fig. 3 utilizes three direct coupled symmetrical limiters. Exceptionally good AM rejection results, and normally cannot be measured with commercial AM-FM signal generators because of the inherent incidental phase modulation of the AM-FM generator. The exceptionally wide bandwidth of the cascaded limiters also minimizes the effects of multipath distortion.

When initiating SCA transmission, another potential problem exists. A few of the regular listeners will complain of "birdies" or "whistles" in the stereo signal they receive. The station transmissions will be clean, the SCA program is satisfactory, and the reported "birdies" or "whistles" do not appear on the majority of stereo receivers in the station listening area.

This type of interference is generated by design deficiencies which exist in some FM stereo tuners/receivers, presently in use. It is created by generation of a 57-kHz signal (third harmonic of the 19-kHz pilot carrier) in a switching-type stereo demodulator, utilizing diode switches. In an identical manner to the previous caution relating to third harmonic generation in the station stereo generator, this 57-kHz signal produces a 10-kHz product when beat with the 67-kHz subcarrier which is included in the composite input signal to the stereo demodulator. When the subchannel is FM modulated, the reported "squishy" sound results. *This effect is generated in the listener's receiver!*

Square-wave switching demodulators, although capable of excellent stereo separation and stability, are the worst offenders.

A number of current stereo receivers utilize these demodulator designs but minimize SCA interference by use of a filter preceding the diode-switching demodulator. These filters ideally should provide a flat passband and linear phase response up to 53 kHz and infinite attenuation from 60 to 75 kHz. Filters providing these characteristics are relatively expensive and compromise designs vary from simple, low-cost to fairly exotic versions, at the sacrifice of stereo separation at the higher audio frequencies. Unfortunately, some receivers, even those in the higher price range, and of otherwise highest quality, have poor or no SCA filters!

An additional potential source of "receiver-generated" interference is in the 38-kHz regenerated stages where the 19-kHz pilot carrier is amplified, doubled in frequency and injected into the stereo demodulator. This regenerated 38-kHz signal must be absolutely free of any 19- or 76-kHz component. The presence of a second harmonic signal at 76 kHz will intermodulate with the 67-kHz subcarrier producing an audible 9 kHz "whistle" in the recovered stereo audio output.

Fortunately, integrated circuit chips incorporating phase lock loop stereo demodulator designs have been developed and are being used in more and more new consumer-electronics receiver designs. These inherently offer excellent SCA rejection and superior stereo separation at the higher audio frequencies.

A good deal of publicity has been generated on the subject of quadraphonic (four-channel) FM broadcasting as a supplemental service to existing stereophonic transmission. This has caused concern as to the effect on SCA channels.

First, the present FCC rules pertaining to stereo broadcasting permit the use of matrix-type four channel encoder/decoder systems which are fully compatible with present stereo systems. The use of matrix four-channel systems presents no conflict with the SCA channel since the channel interrelationships are identical to those for current stereo/SCA transmission.

Under the auspices of the Electronic Industries Association (EIA), a National Quadraphonic Radio Committee (NQRC) was established for the purpose of evaluating discrete quadraphonic systems developed by five proponents. The five systems were tested in "on-air" tests late in 1974, using the facilities of K-101 in San Francisco. *The EIA/NQRC tests included measurements to insure compatibility with SCA transmission.* All proposed systems met this criterion. Some of the proposed systems retain the present 67-kHz SCA carrier frequency, while others contemplate the use of an SCA channel at 95 kHz. While a 95-kHz SCA carrier would require a 4 to 5 dB greater signal level in fringe areas, the quality of reproduction and signal-to-noise ratios are equivalent to those obtained with a 67-kHz subcarrier frequency.

All of the proposed systems require bandwidths in excess of the present FCC, ± 75 kHz limitation, hence, adoption of any of the proposed systems involves a change in the present rules. The substantial technical data compiled during the K-101 tests will be the basis on which the Commission will consider the establishment of engineering standards and rules pertaining to an FM broadcast quadraphonic system. Since all of the proposed systems under consideration do accommodate an SCA channel, there is no danger that this mode of transmission will become extinct. At worst, the subchannel frequency *may* be changed to other than its present 67-kHz location.

The material discussed to this point has been limited to the broadcasting of aural SCA material. The Commission has recently changed its rules to permit nonaural uses of SCA. Some of these new transmission modes include slow-scan TV, facsimile, teletype, etc. Most of the above referenced modes are regularly transmitted over low-grade telephone circuits. The response, distortion, and signal-to-noise capabilities of an SCA channel substantially exceed those of wire circuits, thus, a revision of Commission rules to permit transmission of nonaural services opens a new dimension of the SCA field.

Licenses have now been granted by the Commission permitting SCA transmissions of slow-scan TV, multichannel teletype, visual display systems, and an aural/visual electronic blackboard system. The technology exists for these new and interesting modes of broadcasting. The adoption of rules permitting these nonaural services on SCA subchannels is a milestone in FM broadcast technology.

STEREOPHONIC BROADCASTING

Stereophonic broadcasting has given both added pleasure to the listener and increased responsibility to the broadcaster. Although stereophonic broadcasting has been permitted by the Federal Communications Commission for over 15 years, there is still a continuing need for the proper understanding of the system's operation and what safeguards must be developed to ensure the transmission of optimum stereophonic signals.

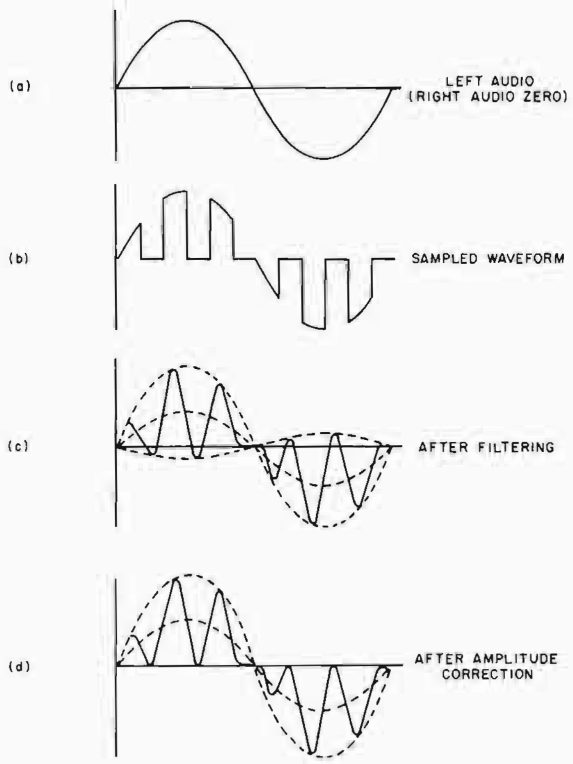

Fig. 4. Time division signal for left = 1, right = 0, L + R = 1, L - R = 1.

System Operation

A good part of the mystery of stereo is related to the way the theory of the system is explained and "(L + R) and (L - R)" tends to confuse the casual observer. Stereo is a time division system and should be explained from that viewpoint. The composite stereo signal, before it modulates the transmitter, is a chopped audio wave with specific time slots labeled Left or Right. The amplitude of the signal within these time slots represents the amplitude of the signal **in that channel at that time.**

Consider some examples of the resulting time signal as it exists at a discriminator after demodulation. (For clarity, the pilot carrier will be neglected for the moment.) In Fig. 4a, a Left audio signal is applied to the transmitter. After being chopped in a 4-diode time modulator, it looks similar to Fig. 4b. This waveform is cluttered with undesirable harmonics of the chopping rate (38 kHz) and is filtered, as in Fig. 4c. Filtering, however, creates an overshoot on the base line of the audio signal. This is an undesirable condition, because overshoot or undershoot represents poor channel separation.

Receivers decode the baseline as an opposite, or Right channel signal, and good separation depends on the baseline being as close to zero as possible. In Fig. 4c, therefore, the baseline signal is corrected with a cancel circuit, and the resultant waveform in Fig. 4d appears at the receiver discriminator. Since it is a chopped signal, the listener hears the average of the signal rather than the peaks, and by comparison it will appear to be 6 dB down from a conventional signal in the normal monaural receiver if no Right channel signal is present. Increasing the amplitude of this signal can cause distortion if its peak amplitude is at full modulation, for the peaks will clip and the average level will be affected.

For an example, put two similar signals on the Left and Right channels as reflected in Fig. 5. (Filtering, though present, is not necessary to explain the resultant waveform in Fig. 5c.) The alternate slots are added and fall into a neat dovetail arrangement, producing a conventional sine-wave signal with some switching imperfections that are disregarded in the receiver. The (L + R) signal, after chopping and reconstruction, closely resembles a conventional monaural audio signal and contributes to the compatibility of the system. Conventional or stereo receivers get the same information if it is applied in equal amplitude to *both* channels; that is, announcements or mono-program material must be applied to both L and R channels to appear distortion-free and be

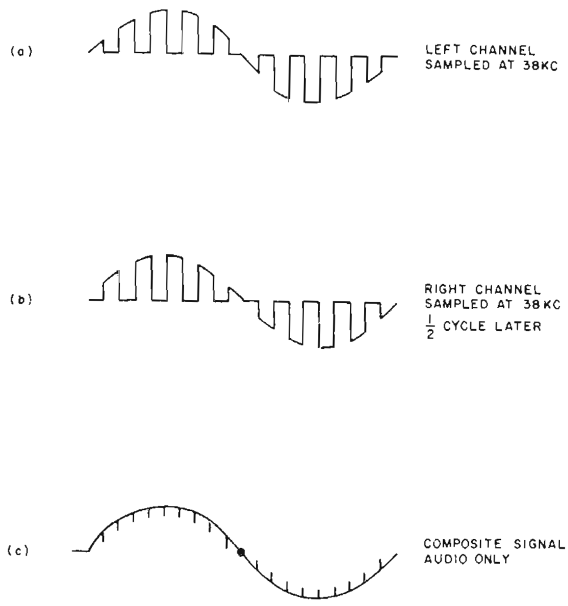

Fig. 5. Time division signal for L = R, L + R = 2, L · R = 0.

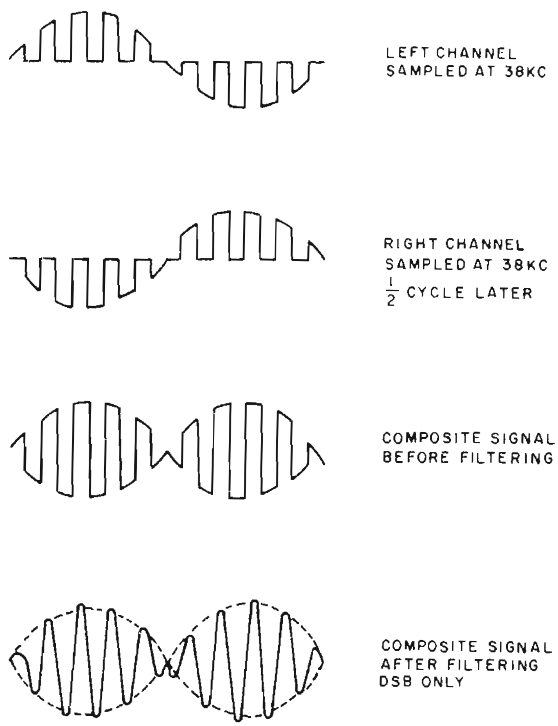

Fig. 6. Time division signal for left = minus right L + R = 0 L · R = 2.

of correct amplitude in all types of receivers. This sometimes creates a problem for stations engaging in AM and FM simulcast programing. Telephone line levels for remote transmitter situations prohibit the forming of a noise-free (L + R) signal to be used for the AM transmitter. In many instances, it proves best to form the AM audio at the console and use a third line for AM programing.

Phasing

Reversing the polarity of the Right channel results in a (L - R) signal, as shown in Fig. 6. Note that the average audio seen by a conventional receiver is zero. This characteristic of the signal furnishes a convenient method of checking the phasing through a system. Using a monaural record on a stereo turntable, the audio lines should be reversed until the loudest audio signal is heard in a monaural receiver. The system is then phased correctly. In a stereo system, the sound should appear to come from a source directly forward of the listener if the record is monaural. If phased incorrectly, the sound will appear to come more from the side, due to some audio cancellation occurring at the ear of the listener. Phasing presents a continuous console problem in day-to-day operation of stereo. It is a requirement that the console operator generally overlooks until the listener complains. It should be stated, however, that many modified stereo consoles present such a complexity to the operator as to require considerable time to master.

Transmitter

There are some basic principles regarding the tighter requirements made on the transmitter. The chopped signal drawn in Fig. 4 consists of two components. One, referred to as the average signal, is an audio component similar to the modulating signal but 6 dB below the peaks of the chopped signal. The second is a double-sideband signal very similar to the (L - R) signal in Fig. 6, with peak excursions of the same amplitude as the audio signal just mentioned. In fact, these signals must maintain peak amplitudes that are equal within 0.3 dB to meet FCC specifications on channel separation. An inequality will show up as an overshoot or undershoot (as in Fig. 4c) on the baseline. Disregarding pilot carrier phase requirements, *the channel separation of any system can be determined by examining this baseline overshoot at the discriminator of a wide band receiver.* Such an overshoot will occur if the amplitudes are not equal and also if the phase of the two components is not precisely correct. The stability of the stereo signal places a tight requirement on phase and amplitude of the audio circuits used to create the signal. It is almost mandatory, for instance, that dc coupling be used between the stereo generator and the modulator.

The synchronizing signal at 19 kHz, the pilot carrier, furnishes the "kick" for the switch in the transmitter and aids the receiver in decoding the L and R channels. Fig. 7 is a picture of an actual

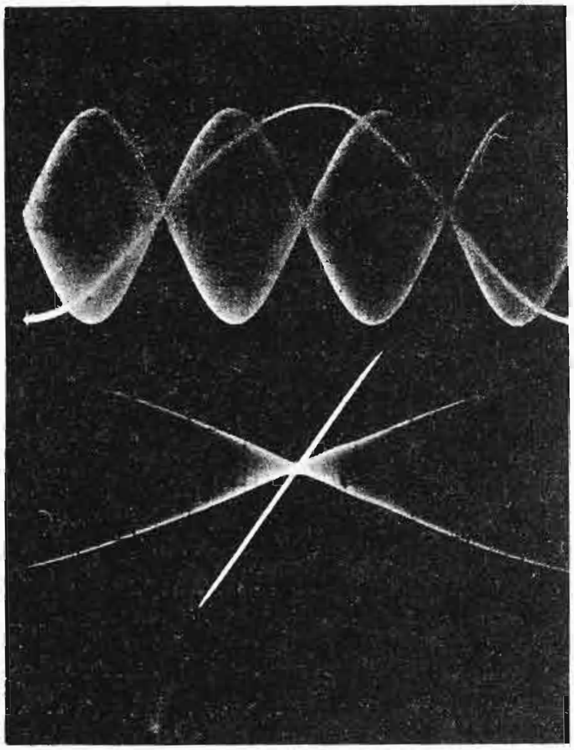

Fig. 7. (A) DSB signal and pilot carrier. (B) DSB signal and pilot carrier expand around the zero crossing.

(L - R) signal (similar to Fig. 6) which was taken in such a way that the audio modulation "fills in" the time slots. Superimposed on this signal is the

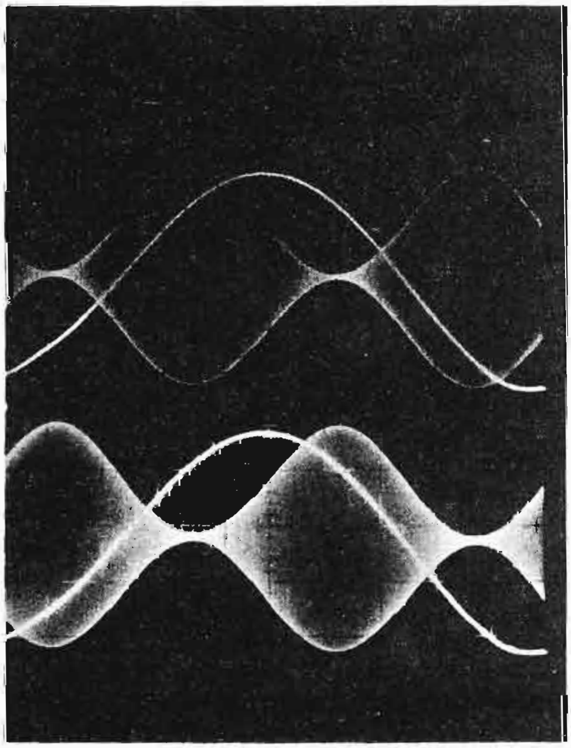

Fig. 8. (A) Left-only signal and pilot carrier. (B) Right-only signal and pilot carrier.

19-kHz pilot carrier. Fig. 7b shows, in expanded sweep, how closely the pilot must be in phase with the zero crossings of the 38-kHz oscillator. The pilot must be within $\pm 3°$ or 1 division on the lower scale to satisfy FCC requirements.

Fig. 8 demonstrates how pilot carrier phase determines that a channel is Left or Right. As stated in the FCC rules, the Left channel is defined as the channel where the 38-kHz zero crossings are positive-going with a positive-going pilot carrier. Fig. 8 represents an expanded version of Fig. 4. Again, modulation fills in the picture, but the signal shown is different from the (L - R) type in that there are no sharp criss-crosses on the baselines. The positive-going zero crossings of the 38-kHz sideband signal can be identified as occurring midway between the valley and the peak of the signal on the left side of the picture. Note that the pilot carrier crosses the zero axis positively at this point. In contrast, the pilot signal is out-of-phase with a positive-going right signal. Since there are two time slots for each cycle of the pilot, only the positive-going portion of the pilot carrier should be studied to avoid confusion. From the theory, it becomes apparent that the method used to generate the stereo signal determines reliability. A four-diode switching circuit accomplishes this in short order (see Fig. 9). Twelve passive, precision components are used to create a stereo audio signal for a wideband modulator. Stability of this signal is dependent only on these components if the exciter is sufficiently stable.

To answer the need for stereo, a wide-band modulator was designed for this time division signal. The principles involved in this modulator-exciter require some detail to explain, but it is sufficient to state that the following objectives are met:

1. The modulator accepts any audio signal from 30 Hz to 75,000 Hz on a single input.
2. The inherent distortion is kept below 0.3 percent at these frequencies.
3. The frequency response is within ± 0.1 dB between 50 Hz and 53 Hz.

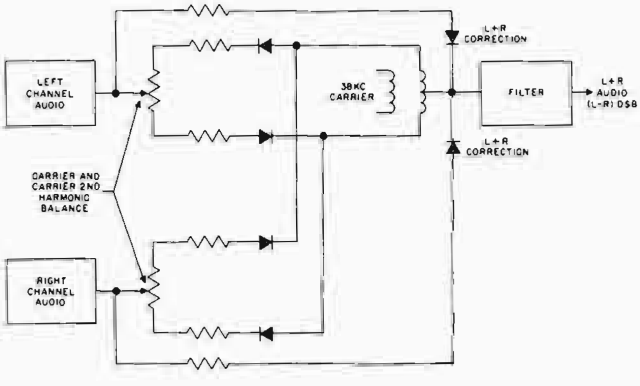

Fig. 9. Stereo generator switching circuit.

4. Frequency stability, including aging, will hold within ±500 Hz of assigned carrier under normal conditions; ±1,000 Hz under the worst conditions of age and environment.

Audio

A proper studio console for stereo considerably reduces production problems in all types of programing. A vital need in the console is to keep the important controls to a minimum to avoid shifting standards of balance and separation during the normal program day. In remote operation, telephone line levels must be matched at the transmitter by adjusting console levels with test tones and left untouched except for periodic checks. Every source must be checked for balance, that is, tape recorders, turntables, microphones. Modulation during programing should be watched by monitoring the outgoing telephone lines with VU meters. Additional remote control features should be added (stereo-mono switch). To achieve close balance, part of the audio circuits should be continuously variable instead of the step-type attenuation frequently used.

Limiters should be installed on each stereo channel. Limiting should be *used sparingly* because program material varies. Stereo performance can be affected by excessive limiting, but a good peak limiter can control modulation where broadcast monitors fail to report true modulation. If possible, the pre-emphasis should be ahead of the limiter to compress high frequencies equally with the lows. There are a number of stereo audio processors which incorporate pre-emphasis as an integral part of their circuit design.

Noticeable also has been the effect of excessive limiting on the mono version of the stereo signal. If the sound is full in one channel and bare in the other, a hiss is introduced by the unused limiter introducing full gain to the system under a maximum limiting condition. The mono listener also may notice a variation of volume level as the monaural version of the stereo signal goes in and out of limiting. The limiters, while providing constant volume in one channel, will be switching between channels as the virtual image of the sound goes from one channel to the other. Elements of the stereo signal under a maximum limiting condition will vary in level and will prove annoying to the mono listener.

Coverage

Stereo coverage of a station, unfortunately, is less than its monaural counterpart. Part of this is involved in the increased use of bandwidth without a corresponding increase in modulation. Because of this and the type of system chosen, background noise increases by 20 dB in the stereo channels over the corresponding noise in the mono (L + R) channel. Such a noise increase is noticeable in receivers with poor limiting characteristics in weak signal areas. As a general rule, reliable reception in stereo occurs out to the 1-mv contour. Beyond that, reception is a function of receiver and antenna characteristics, and listeners should be asked to use good outside antennas in these areas. High quality receivers can produce acceptable stereo at much lower field strengths than 1 mv/m.

The Stereo Record

Stereophonic recordings involve two separate channels of information. In order to achieve the acoustical perspective, depth, spaciousness, and other benefits that are possible, great care must be observed to maintain the proper phase relationship between the two channels of information, both in recording and reproduction. The same care must be observed in FM stereo broadcasting. This is particularly true because the transmission may be reproduced either stereophonically or monophonically, and it is essential that the quality of reproduction be the best possible in either case.

The 45°-45° stereophonic system chosen by the Record Industry Association of America (RIAA) as a standard was selected after careful consideration of the available systems. It was selected, for one reason, because of the compatibility that can be achieved with respect to monophonic reproduction. To achieve this, the RIAA standard states:

> In 45°-45° stereophonic disc phonograph records, equal and in-phase signals in the two channels shall result in lateral modulation of the groove.

As illustrated in Fig. 10 for the 45°-45° system, the two channels of information are recorded in a single groove with the modulation axis of the two systems at right angles with respect to each other, and 45° with respect to the surface of the record. The diagrams at the left and right, A and B, show the type of groove obtained when an identical signal is applied to the left and right coils separately and then together. It is important to note that in Fig. 10c vertical modulation results if the signals are equal in amplitude but out of phase. Likewise, Fig. 10d shows that lateral

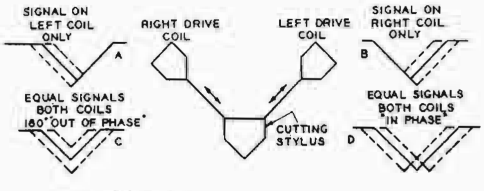

Fig. 10. 45°-45° stereo disc recorder.

modulation results if the two signals are equal and inphase.

In terms of record reproduction, if in the case of 10d the recording is reproduced with a suitable lateral pickup, information from both channels will be present. The sound quality will be like that of a monophonic record that had been cut with a lateral recorder where the signals had been obtained by combining the output of the two channels electrically. If the phase is reversed, as is the case shown in Fig. 10c, the modulation of the groove will be vertical and the results will be poor due to cancellation of the lateral components.

The problem of correct phasing is similar to that which must be observed in stereophonic broadcasting where monophonic reproduction is the sum of the left and right (L and R) channels. The phase relationship is of importance since an incorrect phasing will result in considerable cancellations, particularly at low frequencies. Only if the proper phasing has been observed will the sound quality be satisfactory.

Evaluating Stereophonic Records

A simple method of judging the monophonic quality of a stereophonic record is to reproduce it monophonically. This may be achieved by using a suitable lateral pickup and reproducing the record over a single channel amplifier and speaker system. By suitable is meant a pickup designed for monophonic record reproduction,one that has sufficient vertical compliance to properly track the vertical undulations of a stereophonic record without undue distortion or damage to the groove. A stereophonic pickup with the output leads tied together for monophonic reproduction provides a ready means of providing such a pickup.

Another method and one that might offer greater appeal to the broadcaster is to combine the outputs of the two pickup channels at the outputs of some of the amplifiers along the chain. When doing this, there may be some question about the channel gains and the phase relationship. These may be easily checked by playing a lateral frequency record. The VU meter readings for each channel should be equal. If the phase relationships are incorrect, the single VU meter that reads the combined outputs will show a drop in output as the channels are connected together.

The cancellation of signals due to improper phase relationship when reproducing music records results in a loss in the low frequencies and undesirable high frequency characteristics. When the phase and gain relationships are correct, a properly recorded stereo record will show nearly undetectable tonal balance differences between monophonic and stereophonic reproduction. The stereo reproduction will, of course, exhibit acoustical perspective, depth and spaciousness due to the additional information since it is derived from two channels instead of one.

Phase Checking Methods

Realizing the importance of observing and maintaining the proper phase between the stereo channels, a logical question that arises is: How can one check the phase relationship? Ideally, the two channels should be exact duplicates throughout their operating range. Frequency and phase response should match closely. In general, the phase relationship is the most difficult one to measure. However, with the aid of an audio oscillator and an oscilloscope, simple observations can be made that will determine whether or not the connections are inphase.

If an audio oscillator is connected to an oscilloscope, as illustrated in Fig. 11, with the high side of the oscillator connected to both high side terminals of the oscilloscope, a straight line inclined at a 45° angle to the right should be observed. Since this is a common signal equal in amplitude that is being applied to the oscilloscope, it is obviously the inphase condition. If two signals of the same frequency and amplitude were applied 180° out of phase, a 45° line would be observed which would slope towards the left. A 90° phase shift would result in a circle.

The oscillator and oscilloscope provide a simple set of tools for determining the "in" or "out" of phase conditions. They may be used for microphones and loudspeakers as well as amplifiers. The arrangements for such measurements are shown in Figs. 12, 13, and 14. When acoustic

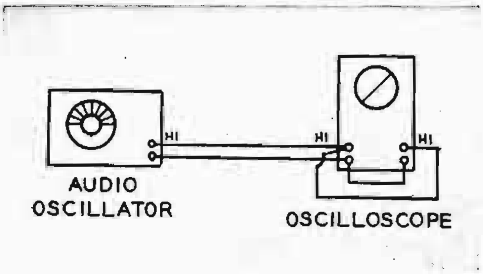

Fig. 11. Phase indicator.

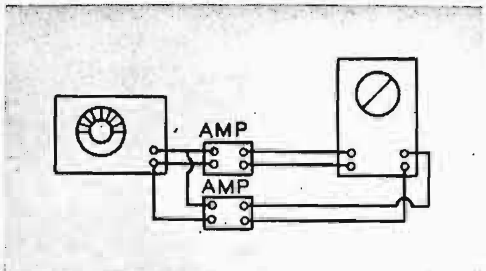

Fig. 12. Checking amplifiers.

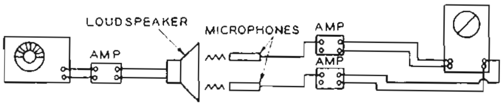

Fig. 13. Checking microphones.

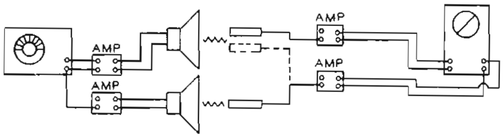

Fig. 14. Checking loudspeakers.

transmission is involved, a low frequency such as 200 Hz should be used to minimize phase differences due to the transmission of the signal through air. When checking loudspeakers as illustrated in Fig. 14, a quick check of the system can be made by first placing both microphones in front of one loudspeaker and noting the trace on the oscilloscope. The same trace should result when the microphone is shifted back to its original position. For checking the phase relationship of high frequency speakers, EIA recommends that direct current be used and the direction of motion of the diaphragm be observed, or a sensitive dc meter be connected across the terminals and the polarity of the voltage noted when the diaphragm is moved manually.