BE

SECOND GENERATION TECHNIQUES
FOR AM STEREO EXCITER DESIGN

BY

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I.   INTRODUCTION.

With the introduction of AM stereo to the broadcast industry, a new trans-
mission mode has been defined with a new set of complex and unique problems to
be overcome. Not only are there multiple systems available to transmit stereo
due to the FCC marketplace decision, but within each system it is possible to
improve the design quality and stereo performance.

During the infancy of AM stereo, there were only the system proponents man-
ufacturing their own equipment. This first generation hardware was not broadcast
quality and often fell short in producing the best possible performance for its
particular system. Controls for alignment and operation were frequently inacces-
sible.

Today there is a great need for more flexible and reliable hardware.
Motorola, Inc., the inventor of the C-QUAM[*] system, has licensed several experi-
enced broadcast equipment manufacturers to fill this need. This presentation

[*] C-QUAM is a registered trademark of Motorola, Inc.

will review some of the improvements and new approaches developed by Broadcast Electronics, Inc. during the design effort for the AX-10 exciter: an all new, second generation C-QUAM AM stereo system.

II. SECOND GENERATION REFINEMENTS.

After reviewing the currently available hardware for AM stereo, several areas for improvement were discovered. Many of these improvements were based on state of the art design techniques employed in the BE FX-30 FM exciter and the BE FS-30 FM Stereo Generator. Others were new innovations developed to improve the C-QUAM system performance. These refinements include:

1. Digital, independent IF modulation technique.
2. Simplified transmitter interfacing.
3. Extended RF output power range.
4. AM SCA capability.
5. Transmitter protection circuitry.
6. Balanced, transformerless audio inputs and outputs.
7. External reference capability to eliminate "platform motion".
8. Human engineering for easy accessibility.
9. Remote control and status.

2.1 Digital, Independent IF Modulation.

Digital, independent IF modulation is the heart of the BE AX-10 AM stereo exciter. All clock signals are derived from a single 10 MHz temperature compensated crystal oscillator (TCXO). This highly stable reference improves overall stability. The stereo signal is generated at an intermediate frequency of 250 kHz for all station frequencies assuring equal stereo performance across the entire AM band. Each audio channel is modulated separately, then summed to L+R

and L-R, hence the term independent IF modulation. This scheme provides independent equalization of left and right channels for best separation, distortion and frequency response. The total system provides a stable carrier frequency output across the AM band without successive retuning or nulling, and with repeatable stereo performance at all frequencies.

Figure 1 shows the conventional matrix modulation approach to C-QUAM stereo generation. The summed L+R information, together with a DC offset to produce a carrier [1+M, (S(t))] is modulated with a $\emptyset$ degree RF signal [Ac (COS ω ct)]. The difference L-R information [M2(D(t))] is modulated with an RF signal phase shifted by 90 degrees [Ac (SIN ω ct)]. These two signals are summed, providing a quadrature modulation signal [Xc(t)]. At this point, stereo information is fully present and can be decoded by a synchronous detector. However, this signal is not mono compatible on an envelope detector. Therefore, it is amplitude limited to produce a quadrature phase-only signal [Yc(t)]. This phase modulated RF signal is then amplitude modulated with the 1+M, (S(t)) signal in the AM transmitter to produce the mono compatible C-QUAM signal [Zc(t)].

Figure 2 describes a fully independent modulation C-QUAM stereo system developed by Broadcast Electronics. In this configuration, the left channel [M3(L(t))] is modulated with a 90 degree phase referenced RF signal [Ac (SIN ω ct)] to produce Qc(t). The right channel [M4(R(t))] is modulated with a 270 degree phase referenced RF signal [-Ac (SIN ω ct)] to produce Tc(t). These two signals are summed to produce Wc(t).

M3(L(t)) is also summed with a DC offset to produce a carrier signal of half-magnitude, then modulated with a $\emptyset$ degree phase referenced RF signal [Ac (COS ω ct)] to produce Pc(t). M4(R(t)) is summed with a DC offset of half-magnitude, inverted, then modulated with a 180 degree phase referenced RF signal [-Ac (COS ω ct)] to produce Nc(t). These signals are summed to produce Vc(t).
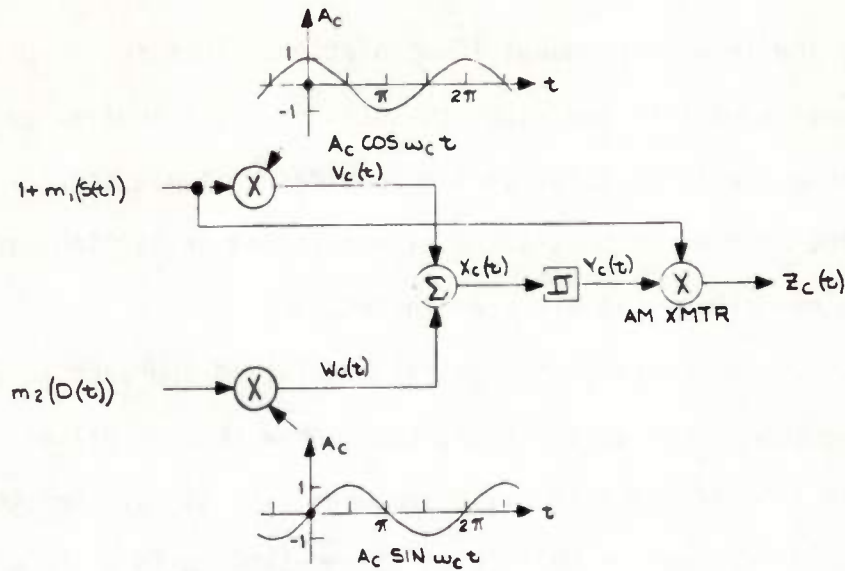
I. $V_c(t) = [1 + M_1(S(t))] A_c \cos \omega_c t$ (a)

    $W_c(t) = M_2(D(t)) A_c \sin \omega_c t$ (b)

    Where $M_1(S(t))$ and $M_2(D(t))$ are the sum and difference modulating

       components respectively.

II. $X_c(t) = A_c [[1 + M_1(S(t))] \cos \omega_c t + M_2(D(t)) \sin \omega_c t]$

    $= A_c \sqrt{[1 + M_1(S(t))]^2 + M_2(D(t))^2} \; \cos(\omega_c t + \theta)$

       Where $\theta = \tan^{-1} \left[\dfrac{M_2(D(t))}{1 + M_1(S(t))} \right]$
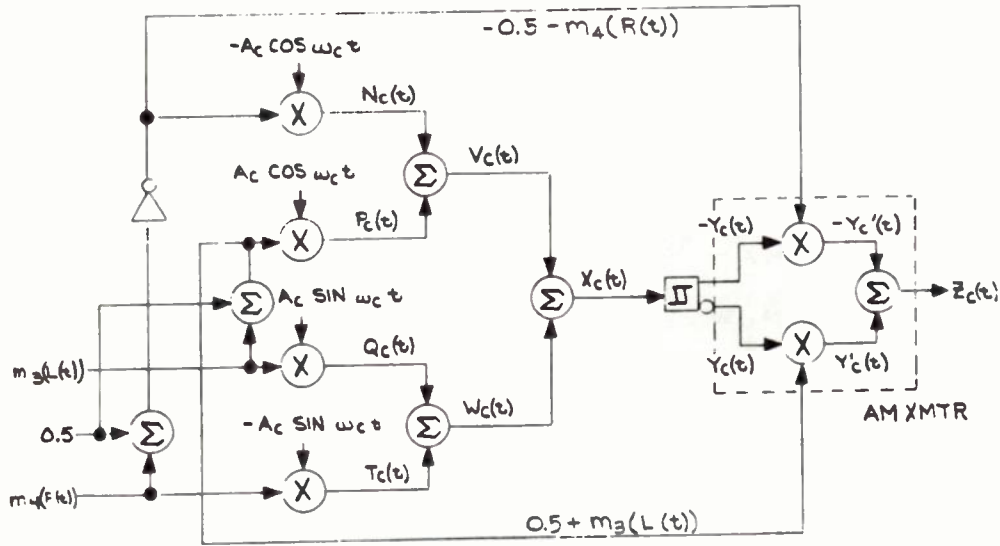
    $X_c(t)$ Represents Quadrature Modulation

III. $Y_c(t) = A_c \cos(\omega_c t + \theta)$ (Quadrature Phase Information Only)

IV. $Z_c(t) = A_c [1 + M_1(S(t))] \cos(\omega_c t + \theta)$

    $Z_c(t)$ Represents C-QUAM Modulation

FIGURE 1. CONVENTIONAL MATRIX C-QUAM STEREO GENERATION

Vc(t) and Wc(t) are summed to produce the identical quadrature modulation as in Figure 1 [Xc(t)]. This signal is amplitude limited producing two quadrature phase-only RF signals 180 degrees out-of-phase [Yc(t) and -Yc(t)]. These RF signals are amplitude modulated independently by left channel plus half carrier [0.5+M3(L(t))] producing Y'c(t) and -right channel plus -half carrier [-0.5-M4(R(t))] producing -Y'c(t). These signals are summed to produce the identical C-QUAM signal [Zc(t)].

Figure diagram labels (top to bottom):

$-0.5 - m_4(R(t))$

$-A_c \cos \omega_c t$ → X → $N_c(t)$

$A_c \cos \omega_c t$ → X → $P_c(t)$ → Σ → $V_c(t)$

$A_c \sin \omega_c t$ → X → $Q_c(t)$

$-A_c \sin \omega_c t$ → X → $T_c(t)$ → Σ → $W_c(t)$

Σ → $X_c(t)$

$-Y_c(t)$ → X → $-Y_c'(t)$ → Σ → $Z_c(t)$

$Y_c(t)$ → X → $Y_c'(t)$

AM XMTR

$m_3(L(t))$ 0.5 $m_4(R(t))$

$0.5 + m_3(L(t))$

V. $N_c(t) = [\,-0.5 - M_4(R(t))\,][\,-A_c \cos \omega_c t\,]$

$P_c(t) = [\,0.5 + M_3(L(t))\,][\,A_c \cos \omega_c t\,]$

Where $M_3 L(t) = \dfrac{M_1(S(t)) + M_2(D(t))}{2}$, $M_4 R(t) = \dfrac{M_1(S(t)) - M_2(D(t))}{2}$

$V_c(t) = N_c(t) + P_c(t)$

$\qquad = [\,1 + M_3(L(t)) + M_4(R(t))\,]\, A_c \cos \omega_c t$ Equivalent to I(a)

VI. $Q_c(t) = M_3(L(t))\, A_c \sin \omega_c t$

$T_c(t) = M_4(R(t))\, -A_c \sin \omega_c t$

$W_c(t) = Q_c(t) + T_c(t)$

$\qquad = [\,M_3(L(t)) - M_4(R(t))\,]\, A_c \sin \omega_c t$ Equivalent to I(b)

VII. $-Y_c'(t) = 0.5\, A_c \cos(\omega_c t + \theta) + M_4(R(t))\, A_c \cos \omega_c t + \theta)$

$Y_c'(t) = 0.5\, A_c \cos(\omega_c t + \theta) + M_3(L(t))\, A_c \cos \omega_c t + \theta)$

VIII. $Z_c(t) = -Y_c'(t) + Y_c'(t)$

$\qquad = A_c\,[\,1 + M_3(L(t)) + M_4(R(t))\,]\cos(\omega_c t + \theta)$

Which is equivalent to IV.

FIGURE 2. B.E. INDEPENDENT MODULATOR C-QUAM STEREO METHOD

This configuration has the potential of having completely independent equalization of left and right channels, but has one serious problem. Currently, there are no AM transmitters available that can accept a differential RF signal and have capabilities for independent modulation. Therefore, a modified independent modulation system was developed for use in the BE AX-10 exciter. This is shown in Figure 3.
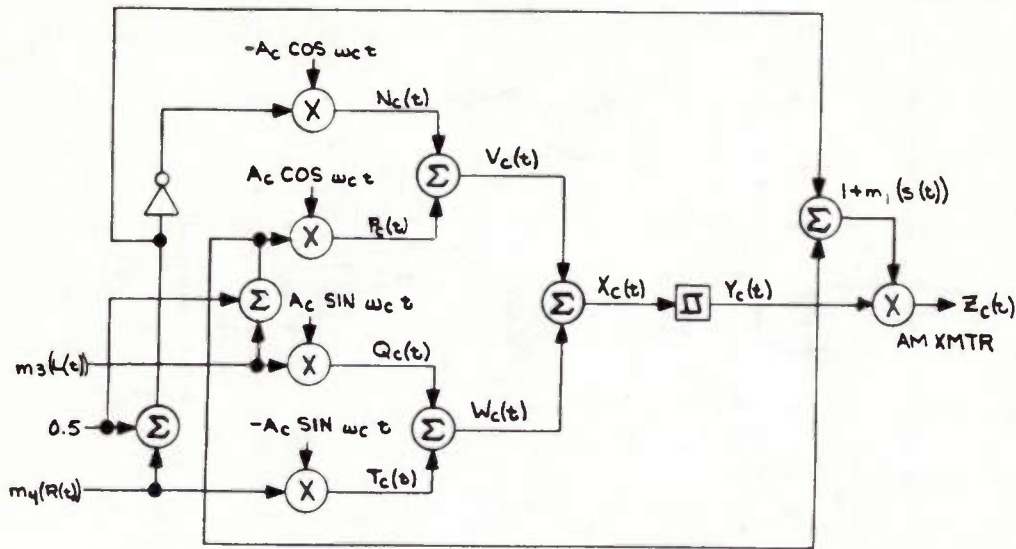
FIGURE 3. MODIFIED INDEPENDENT MODULATOR SYSTEM
FOR USE WITH EXISTING AM TRANSMITTERS

In this configuration, the left channel [M3(L(t))] is modulated with a 90 degree phase referenced RF signal [Ac (SIN ωct)] to produce Qc(t). The right channel [M4(R(t))] is modulated with a 270 degree phase referenced RF signal [-Ac (SIN ωct)] to produce Tc(t). These signals are summed to produce Wc(t).

M3(L(t)) is also summed with a DC offset to produce a carrier signal of half-magnitude, then modulated with a 0 degree phase referenced RF signal [Ac (COS ωct)] to produce Pc(t). M4(R(t)) is summed with a DC offset of half-magnitude, inverted, and modulated with a 180 degree phase referenced RF signal [-Ac (COS ωct)] to produce Nc(t). These signals are summed to produce Vc(t).

Vc(t) and Wc(t) are summed to produce the identical quadrature modulation as shown in Figure 1 and Figure 2 [Xc(t)].

From this point, the system is identical to that of Figure 1. It is amplitude limited to produce a quadrature phase-only signal [Yc(t)]. This phase modulated RF signal is then amplitude modulated with the 1+M,(S(t)) signal in the AM transmitter to produce the mono compatible C-QUAM signal [Zc(t)].

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While the end result in the transmitter is a matrix type modulation, the phase modulated RF signal is derived through independent modulators, thereby providing much less interaction of left and right channels. Although the derivations and diagrams for the fully independent and the modified independent modulation techniques appear much more complex than their matrixed counterpart, in reality the circuitry remains virtually the same.

2.2 Transmitter Interfacing Requirements.

In any AM stereo system employing some form of phase modulated RF signal combined with conventional audio amplitude modulation of that signal, equalization must be used in the phase modulated signal and/or the mono audio signal to the transmitter. This is necessary to match the time delay characteristics of the two paths to construct the proper C-QUAM sideband distribution at the transmitter output, thereby insuring correct de-matrixing to left and right channels in the receiver. Figure 4 shows the relationship of amplitude and phase matching required between the mono L+R signal and the phase modulated L-R signal to achieve any given separation when de-matrixed.

Due to the wide variety of AM transmitters in use today, the task of equalizing these paths to transmit accurate stereo becomes complex. Equalization requirements differ greatly from one transmitter to another, but in most cases the required equalization can be divided into three sections:

1. Group delay in either the RF or transmitter audio path to match the propagation differences between the two.

2. Some form of phase and amplitude correction for higher frequencies due to transmitter and antenna bandwidth/phase characteristics.

3. Low frequency phase correction in some cases.
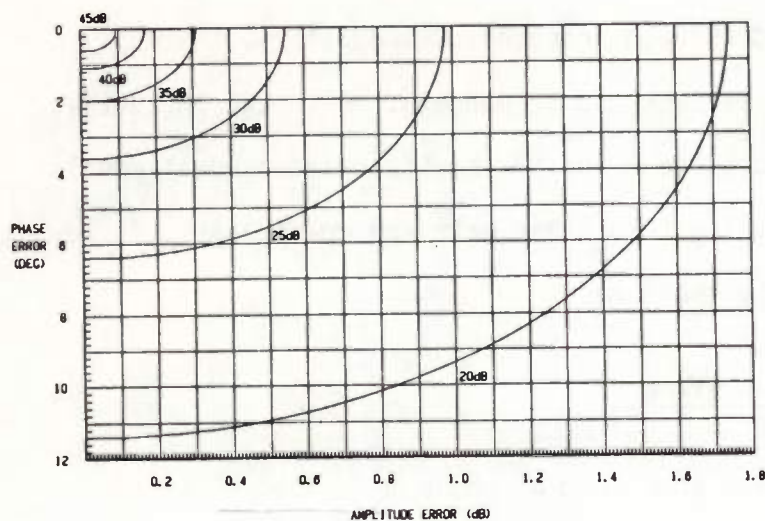
General Equation:

Separation $(A,\theta) = \left[\dfrac{(\cos\theta + A)^2 + (\sin\theta)^2}{(\cos\theta - A)^2 + (\sin\theta)^2}\right]^{\frac{1}{2}}$

Where: $A = \dfrac{L-R}{L+R}$ Amplitude ratio

$\theta = \dfrac{L-R}{L+R}$ Phase error in degrees

FIGURE 4. STEREO SEPARATION AS A FUNCTION OF AMPLITUDE AND PHASE RESPONSE

Determining the exact requirements for a particular transmitter can be a confusing task, and often a series of trial-and-error experimentation results. This process involves trying various equalizers in the RF and audio paths, thereby testing their effect on stereo separation and distortion. Until specific transmitter equalization requirements are documented, alignment will prove to be an involved undertaking.

Because of the need to route any or all of the equalization circuits to either the RF or transmitter audio paths, some form of "patch bay" setup would be advantageous for block equalization selection. In the BE AX-10, this patch bay approach is accomplished by miniature matrix switches accessible under the top cover (see Figure 5). Once the basic layout of the switch is understood, it becomes extremely fast and easy to select any equalization and to route its output to either the input of another equalization block, or directly to the required path.

The type and amount of available equalization varies from exciter to exciter, but in general it can be said the greater the available range of equalization, the more transmitters can be easily converted to transmit AM stereo.

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As an example of one set of equalization, the next few paragraphs will discuss in detail the equalization circuitry used in the BE AX-10 exciter. The amount of available equalization was chosen after researching AM stereo consultants and users.
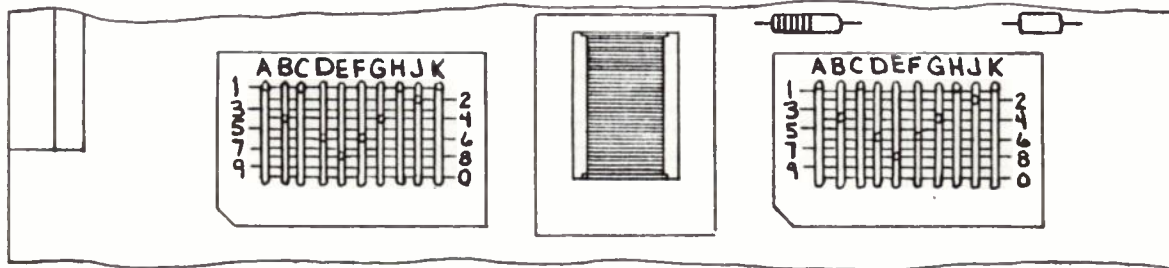

FIGURE 5. MATRIX SWITCHING

Two identical and independent sets of equalization are provided for day and night correction of changing antenna patterns, low power setting, or for a stand-by transmitter. Day/night equalization selection and status are remote control-lable with either momentary ground closure, or by constant ground closure which may be initiated by antenna selection.

It was found that some AM stereo exciters did not contain enough available group delay. Systems may require more than 40 microseconds of delay. For that reason, any amount of constant group delay from 0 to 66 microseconds can be se-lected. This is accomplished by a miniature rotary switch selecting coarse delay in 4 microsecond increments followed by a 0-6 microsecond fine delay adjustment (see Figure 6). In addition, by routing day equalization through night equaliza-tion via the matrix switching, a single equalization of 0-132 microseconds of group delay is possible. So far, only the RCA BTA-5SS solid state transmitter has required more than 60 microseconds. This installation required over 100 microseconds of group delay equalization. The amplitude response remains con-stant in this equalizer from 20-20,000 Hz.

The low frequency phase equalizer is primarily required by plate modulated AM transmitters to correct for time delays introduced at low frequencies by the plate transformer. Figure 7 shows that this first order all-pass network provides a Ø to 90 degree phase shift maximum at 100 Hz while maintaining flat frequency response.
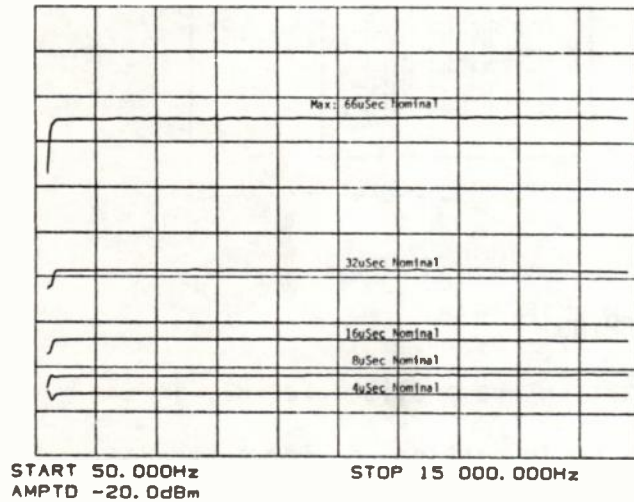
REF LEVEL   /DIV
0. 0SEC   10. 000μSEC

Max 66uSec Nominal

32uSec Nominal

16uSec Nominal
8uSec Nominal
4uSec Nominal

START 50. 000Hz
AMPTD -20. 0dBm   STOP 15 000. 000Hz

FIGURE 6.   GROUP DELAY

REF LEVEL   /DIV
0. 000dB   0. 500dB   AMPLITUDE / PHASE
0. 0deg   20. 000deg   FIRST ORDER ALL-PASS NETWORK

MAX (90° @ 100Hz)

45° @ 100Hz)

18° @ 100Hz

MIN (1° @ 100Hz)

START 20. 000Hz   100   1K
STOP 2 000. 000Hz
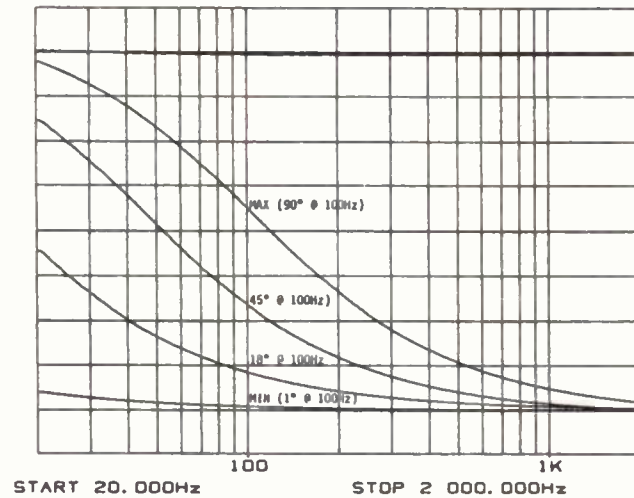
FIGURE 7.   LOW FREQUENCY EQUALIZATION

REF LEVEL   /DIV
0. 000dB   5. 000dB   AMPLITUDE / GROUP DELAY
0. 0SEC   10. 000μSEC   MINIMUM PEAKING -3dB
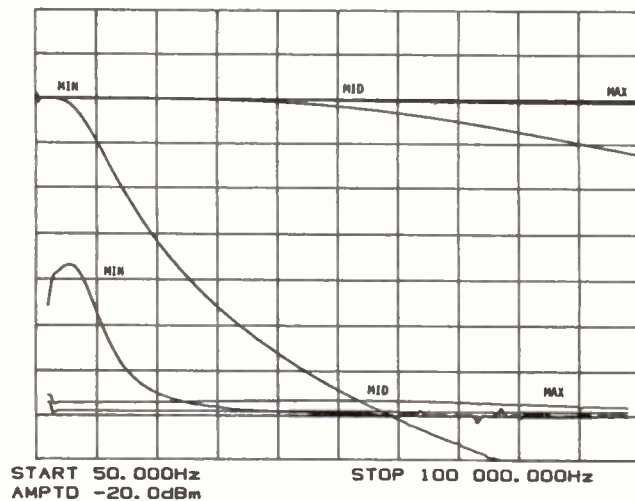
MIN   MID   MAX

MIN

MID   MAX

START 50. 000Hz
AMPTD -20. 0dBm   STOP 100 000. 000Hz

REF LEVEL   /DIV
0. 000dB   5. 000dB   AMPLITUDE / GROUP DELAY
0. 0SEC   10. 000μSEC   MAXIMUM PEAKING +3dB

MIN   MID   MAX

MIN

MID   MAX

START 50. 000Hz
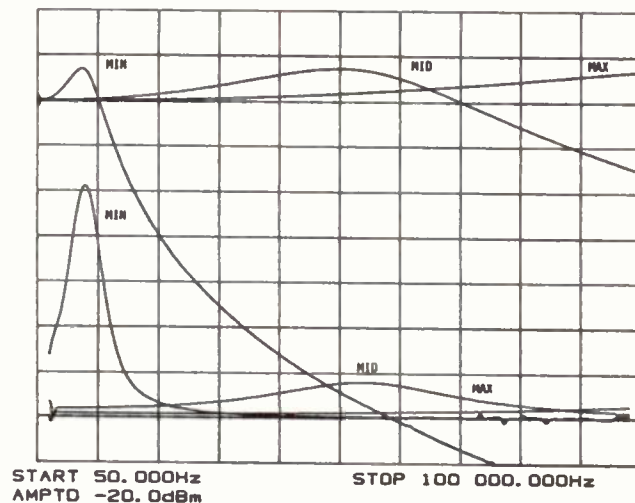AMPTD -20. 0dBm   STOP 100 000. 000Hz

FIGURE 8.   HIGH FREQUENCY EQUALIZATION

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Due to the different phase and amplitude responses of the RF and transmitter audio chain at higher frequencies, correction must be made to provide good separation and distortion. Figure 8 shows some typical responses used to equalize the system at high modulating frequencies. Because of the separate turnover and peaking available, the responses can be tailored to fit the particular installation.

Another interfacing requirement for the exciter is the available range of RF output power. It is generally better to inject the RF signal as far as possible into the transmitter to diminish the effect of bandpass or lowpass filters in low level stages. These filters will degrade overall stereo performance and must be corrected with equalization circuitry in the exciter. By providing 150 milliwatts to 10 watts RMS, a suitable insertion point should be found for good stereo performance. 150 milliwatts into 50 Ohms corresponds to standard TTL signal level to drive transmitters with digital inputs. Some digital transmitters require an asymmetrical duty cycle square wave for best performance. In this case, an optional TTL interface provides from 25% to 75% continuously adjustable duty cycle.

In an effort to remove any phase and amplitude mismatches between the RF and transmitter audio chain due to audio transformers, the mono envelope signal from the exciter is actively balanced. A high output level of +20 dBm provides additional headroom and permits the use of lossy modulation enhancement devices. This output is continuously variable to accommodate transmitters with different input level requirements and more importantly, to exactly match corresponding L+R to L-R levels for good separation and crosstalk. For those transmitters requiring different daytime and nighttime audio levels, separate output level adjustments are included.

2.3 AM SCA.

With the recent FCC deregulation of AM SCA, AM stations are now able to use subsonic phase modulation for services such as load management. For conventional mono AM stations, this requires additional equipment. For AM stereo stations, however, the addition of AM SCA can be extremely simple.

Figure 9 shows the block diagram for the AX-10 pilot tone and AM SCA insertion method. The information to be phase modulated as AM SCA is inserted via the rear panel "Auxiliary Pilot Input". This signal is lowpass filtered to insure higher frequency components are not transmitted, then summed with the digitally derived and filtered 25 Hz pilot tone. This signal is then summed differentially with the left [M3(L(t))] and right [M4(R(t))] channel information for modulation (refer to Figure 3).
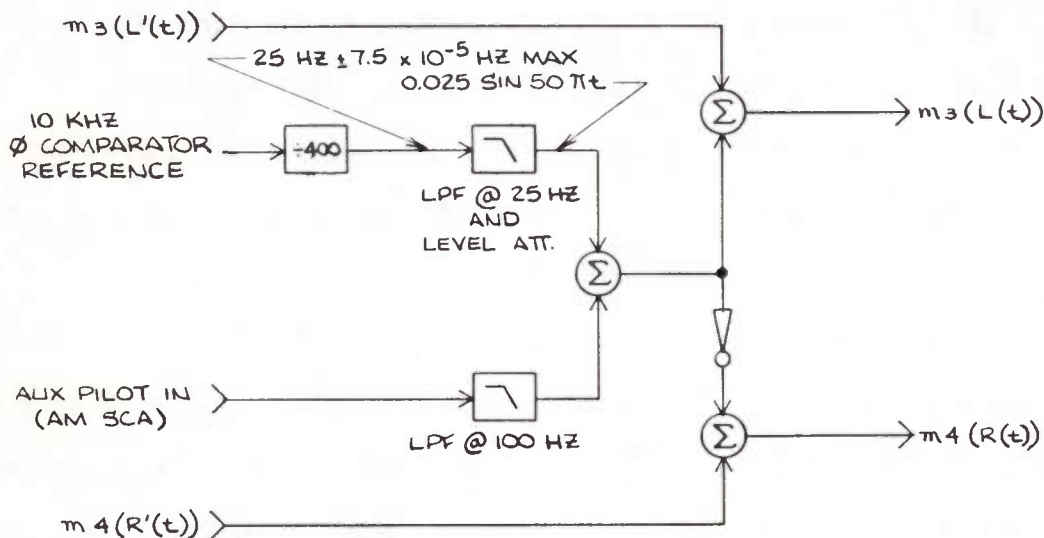

FIGURE 9. PILOT TONE AND AM SCA INSERTION CIRCUITRY

2.4 Transmitter Protection.

In any transmission system using a frequency synthesizer to derive individual station frequencies, some form of muting signal should be included during initial lockup time, or if phase lock is lost during normal operation. For safety reasons, a muting signal must be available if the exciter fails to output

RF to the transmitter. Some transmitters can be seriously damaged if RF drive is lost.

Figure 10 details the transmitter protection circuitry in the AX-10 exciter. If the synthesizer loses phase lock or if a loss of RF presence is detected at the output, an external open collector mute signal is initiated to drive a 40 mA ground closure. This signal could be used to remove high voltage to protect the transmitter. Internal to the AX-10, the mute signal will extinguish the day or night LED on the front panel as a local indication.
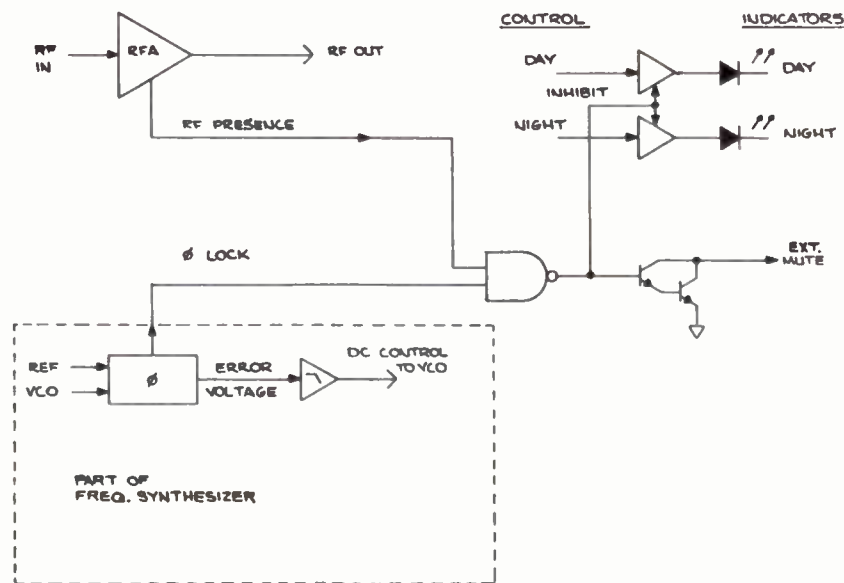

FIGURE 10. B.E. AX-10 PHASE LOCK AND RF PRESENCE PROTECTION CIRCUITRY

2.5 Audio Circuitry.

The audio inputs of an exciter should be completely transparent to the applied program content. Some desired characteristics include:

1. Actively balanced inputs.

2. High common mode rejection ratio (CMRR).

3. Good transient response.

4. Low distortion and noise.

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5. Flat frequency response from 1 Hz to 15 kHz.

6. Identical phase and amplitude characteristics for both
   inputs.

Transformers are capable of balanced input, CMRR and acceptable noise and distortion, but are lacking in transient response, frequency response, phase and amplitude matching of inputs. Incorrect phase and amplitude matching will result in poor main-to-sub and sub-to-main crosstalk, just as poor amplitude and phase matching of main and sub channel response throughout the transmitter results in poor separation (refer to Figure 4).

Fully balanced instrumentation inputs are capable of frequency response from DC to well above 15 kHz, distortion below 0.005%, signal to noise of greater than 100 dB, excellent CMRR, and superior transient response. They also provide excellent phase and amplitude matching.

2.6 External Reference Capability.

For AM stereo systems employing phase modulation, nighttime co-channel interference known as "platform motion" can occur under some conditions. While this phenomenon occurs only in fringe areas where even mono reception is poor, there has been some concern about its presence. Platform motion is caused by co-channel stations having a slightly different station frequency due to the time-base employed. In AM stereo, a rotational effect is created as the receiver decodes the frequency difference from one channel to another at a rate equal to the difference in frequency of the co-channel stations. Because the AX-10 is a digital modulation system deriving all station frequencies from one 10 MHz source, the master oscillator can be replaced with a reference source from WWV or some other standard. If all co-channel stations become frequency locked, platform motion is eliminated.

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Figure 11 shows the frequency conversion technique used in the AX-10. The
10 MHz master clock is used to generate all other frequencies. If the internal
oscillator is used, this reference will be within ±30 Hz from 0-50 degrees C.
The tolerances after the other clock frequencies are maximum deviations due to
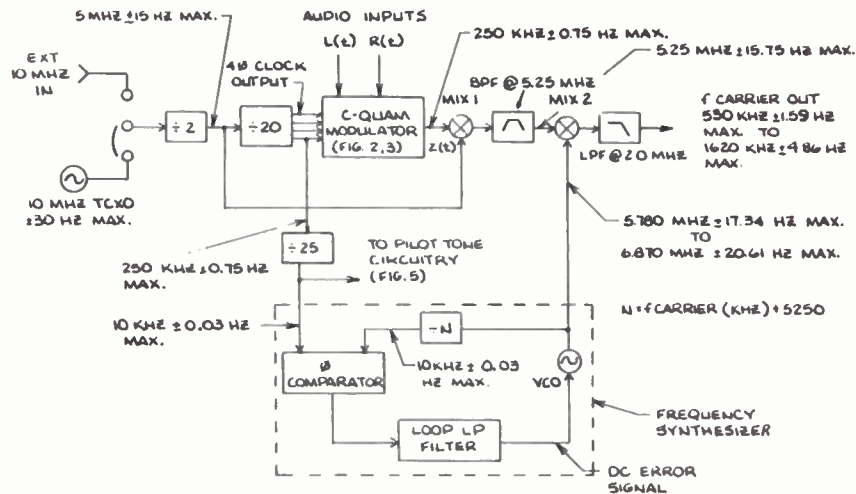the TCXO employed.

FIGURE 11. FREQUENCY COVERSION TECHNIQUE

The 10 MHz is first divided by 2 to obtain 5 MHz. This is used in two
places. First, it is divided by 20 to obtain a 4 phase clock generator at 250
kHz to drive the IF C-QUAM modulator. After stereo generation, the 250 kHz
signal is mixed with the second 5 MHz signal, thereby up-converting to 5.25 MHz.
This second IF frequency passes through a linear phase bandpass filter to remove
other mixing products.

Phase 0 from the 250 kHz clock generator is divided to 10 kHz to provide a
reference frequency for the synthesizer. This synthesizer operates from 5.780
MHz to 6.870 MHz. This frequency is mixed with the second IF frequency of 5.25
MHz to produce a difference frequency from 530 kHz to 1620 kHz which is lowpass
filtered to remove higher order mixing products. The up-down conversion scheme
provides a frequency agile system without retuning and eliminates the need for
individual bandpass filters assigned to the station's carrier frequency. The

difference term from the last mixer is free of images in the AM band. Since there are no bandpass filters or other tuning adjustments specific to the station frequency, the AX-10 can be quickly moved to any channel assignment by simply reprogramming the frequency synthesizer. This technique also guarantees identical stereo performance across the AM band.

Because the synthesizer is phase locked to the master clock and high side injection is used in the last mixer (i.e. the difference term is the one of interest), the frequency errors due to crystal drift subtract, thereby increasing frequency stability. This provides a total error of no more than 5 Hz at carrier frequency across the entire AM band over the 0-50 degree C rating of the TCXO.

2.7 Human Engineering.

Due to the need for flexible interfacing capabilities, any AM stereo exciter must contain a wide range of adjustments from audio, RF and pilot levels to transmitter equalization controls. Accessibility to these controls is of prime importance to the engineer who must align and maintain the exciter. It would be most advantageous for these controls to be available without removal of the unit.

Not all adjustments require immediate access, however there are some which need to be readily available. These include:

1. Transmitter equalization controls (day/night).
2. Transmitter audio level (day/night).
3. RF output level control.
4. Pilot injection level.

Beyond these, any user helpful controls such as mode selection, pilot off switch, single channel limiter defeat switch, manual day/night equalization selection switch, or any required monitoring or diagnostic ports should also be located on the front panel. Should access to internal circuitry be required,

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the exciter is mounted on standard 19" slide rails for convenience. The top
cover can be easily removed. Care must be taken to insure good RFI shielding
for AM, FM, and TV frequencies.

Figure 12 shows the location of controls on the AX-10 exciter. All trans-
mitter equalization controls, together with transmitter audio levels, RF output
level, pilot injection level, pilot off switch, mode selection, single channel
limiter defeat, local day/night equalization selection, and an audio monitoring
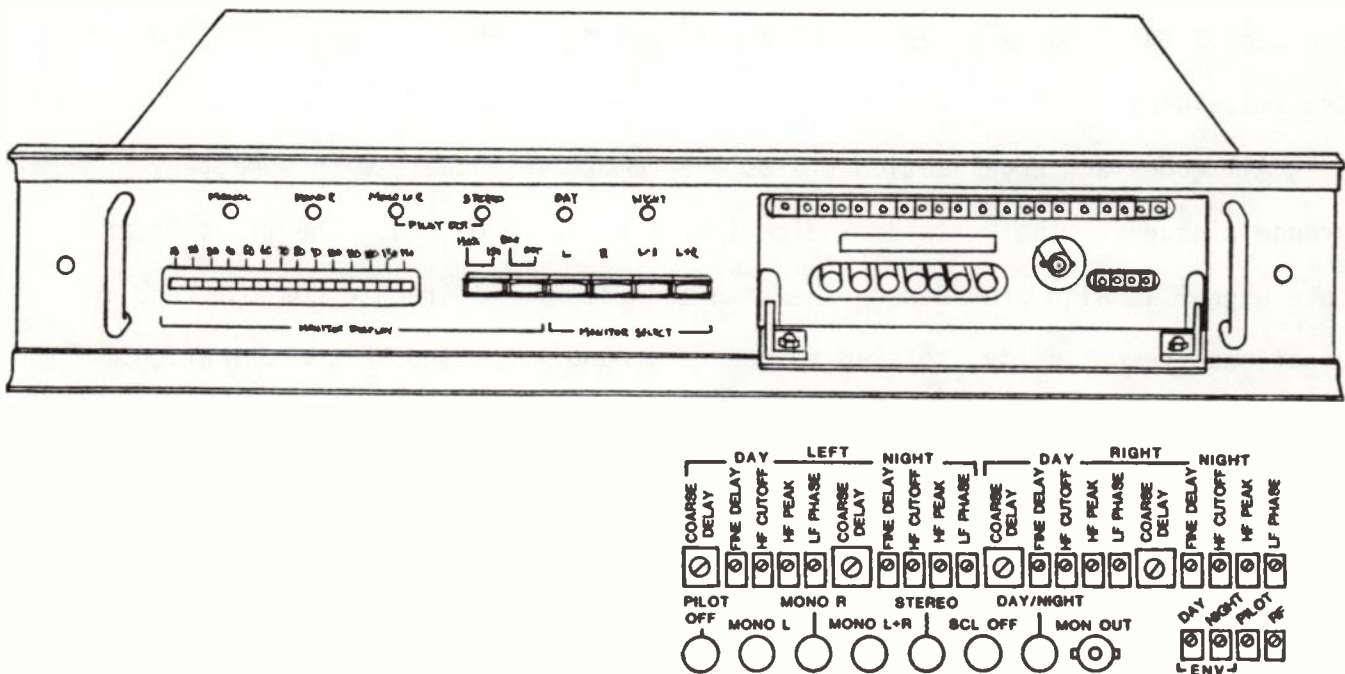point are located behind the front panel door.

FIGURE 12. AX-10 ALIGNMENT CONTROL LOCATION

2.8 Remote Control and Status Indication.

Under no circumstance should there be any loss in mono loudness to the mono
listener during a stereo broadcast, and in fact under normal operating conditions
there is not. It is possible, however, to lose up to 6 dB of mono loudness if
one audio input to the stereo exciter is lost. For this reason, some form of
alternate mode selection should be used. The exciter should be capable of single

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channel operation with no loss in mono loudness.

The BE AX-10 can be run in one of four modes:

1. Mono Left

2. Mono Right

3. Mono L+R

4. Stereo

If one channel to the exciter should fail, the unit can be switched to the opposite channel with no loss in mono loudness. In all mono modes, the 25 Hz pilot tone is muted to return the C-QUAM only receivers to their mono state. Because of this, the exciter can be run in the Mono L+R mode during long mono transmissions.

All modes and equalization states are remote selectable with momentary ground closures. Their status indications are also provided. The transmitter mute signal is also provided on the same connector. All remote controls and indications are optically isolated to reduce ground loops and RF contamination. The inclusion of a standard remote system removes the need to add additional interfacing equipment in the field. It also speeds changeover time to mono modes in case of failure.

III CONCLUSION

Figure 13 shows the overall block diagram of the Broadcast Electronics AX-10 AM Stereo exciter. This products reflects 20 months of in-depth research and development which has provided the forenamed improvements to the C-QUAM AM Stereo system.

Such second generation design techniques offer improvements to look for in the selection of an AM stereo exciter.
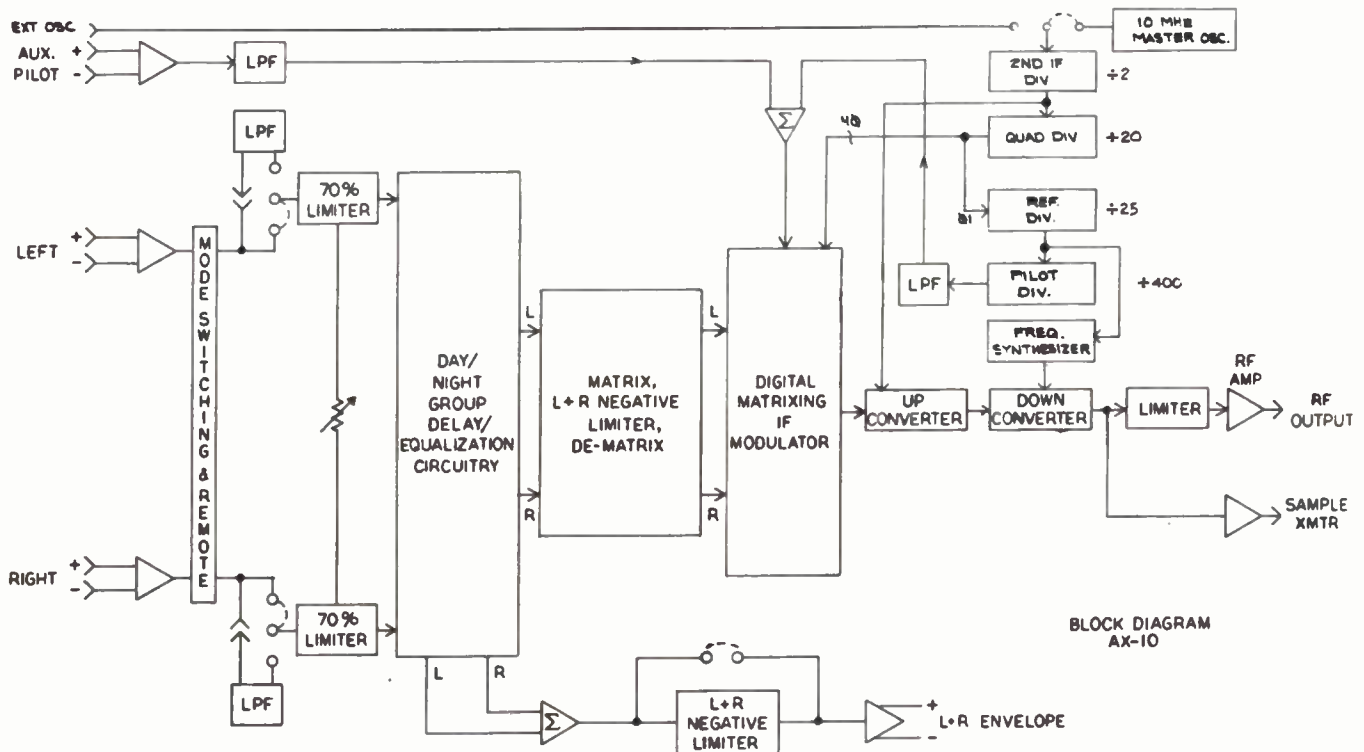
FIGURE 13. AX-10 OVERALL BLOCK DIAGRAM

IV. ACKNOWLEDGEMENTS

I would like to express my appreciation to Mr. Stanley Salek, formerly the AM Stereo Project Engineer at Broadcast Electronics for his design work on the AX-10 and his contributions to the content of this paper. I would also like to thank the members of the engineering and drafting departments at Broadcast Electronics who helped prepare the illustrations and manuscript.

V. BIOGRAPHICAL INFORMATION

Edward Anthony is an Audio Design Engineer in charge of the AM Stereo project at Broadcast Electronics, Inc. in Quincy, Illinois. He has also contributed to the TV Stereo design. Previously, he held the position of Test Engineer at Broadcast Electronics where his main responsibility was implementing test pro-

cedures and supporting the design quality of the FX-30 FM exciter, FS-30 FM Stereo generator and FC-30 SCA generator.

Ed received a BSEET degree in 1982 from Central Missouri State University where he worked as an engineer at KMOS-TV. He is also a member of the Institute of Electrical and Electronics Engineers and a member of Phi Kappa Phi honor society.

VI. REFERENCES

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