OPTIMUM BANDWIDTH FOR FM TRANSMISSION

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INTRODUCTION

For theoretically perfect reception of any frequency modulated (FM) signal, an infinite transmission and reception bandwidth is required. This is due to the nature of FM, which creates an infinite number of sidebands whose structure is determined by the modulation index. In a perfect FM transmitter, the output power remains constant, but as the modulation index changes, the power distribution between the carrier and the sidebands changes.

Practical applications require finite bandwidth restrictions on the FM signal. For the broadcaster, several elements reduce the transmitted bandwidth of the FM signal, including tuned stages in the transmitter grid and output, and the transmitting antenna itself.

For the receiver, the desired signal must be selected, while all others are rejected. This is done primarily by the intermediate frequency (IF) filter. This IF filter is by far the largest contributor to the total RF bandwidth limitation, typically being less than 300 kHz wide (3 dB). Some receivers are available with selectable IF bandwidths of 1 MHz or more. As receiver technology advances, this typical IF bandwidth of less than 300 kHz may very well increase. In any case, broadcasters should not allow receiver shortcomings to limit their efforts to transmit the best possible RF signal.

There is a wide diversity of opinion among both broadcasters and broadcast equipment manufacturers as to the required RF bandwidth for quality FM transmission. At first glance, the "more is better" assumption is likely to prevail. But a closer look reveals some practical considerations which show a need to limit the transmission bandwidth to reduce other problems, especially the ever increasing potential for RF intermodulation in broadcast transmitters.

Therefore, the purpose of this paper is to determine how much bandwidth is required for low distortion FM transmission, and at what bandwidth the point of diminished returns regarding distortion improvement is reached.

Bandwidth Limitations

Several factors contribute to limit the transmitted RF bandwidth of an FM transmission facility. Often, the limiting factor is the antenna system itself. For community tower applications, wideband panel antennas are available. In this case, the hybrid combiners and cavity tuned filters are predominantly the narrowest elements in the transmission path.

The transmitter also plays a role in the total RF bandwidth of a station. Several key areas determine the bandwidth limitations of a transmitter.

A solid state broadcast transmitter is rarely the limiting factor for RF bandwidth. It should be much wider than the antenna, combiners or cavity tuned filters. For tube transmitters the story is much more complex. The output of a high power tube transmitter consists of a frequency selective network in the form of a tuned cavity. The bandwidth of the cavity depends on its construction, the amount of tube output capacitance, and how heavily it is loaded.

The output (cavity) bandwidth is often considered the limiting factor for the whole transmitter. Oddly enough, this is not the case for the grid driven amplifier. The large grid input capacitance of a power vacuum tube causes the loaded Q of the grid circuit to be even higher than the output (1), (2). This fact is often ignored because the grid is driven into saturation which partially masks the amplitude variations of the grid matching network. The popular method of measuring transmitter bandwidth with a network analyzer is somewhat misleading, since the measured 3 dB amplitude bandwidth does not completely account for the grid circuit effects due to saturation. The non-linear response of the power tube further effects the response, especially close to the carrier frequency. This is why accurate predictions of the transmitter 3 dB bandwidth cannot be made by looking at synchronous AM performance, or visa-versa. The amplitude response of the transmitter can be made flatter over a ±75 kHz deviation from carrier due to heavy saturation, heavy loading, and tube impedance non-linearity (3), (4). Measuring this "0.1 dB" bandwidth (-45 dB synchronous AM) proves to be inaccurate when attempting to predict the 3 dB bandwidth from this information. For a properly adjusted transmitter, the synchronous AM performance tends to predict a wider than actual 3 dB bandwidth.

Audio performance is also not completely predictable from a measured transmitter amplitude response. The problem arises from the group delay variations (phase response) of the grid circuit and the non-linear nature of the final tube, which can have serious effects on the distortion performance of the entire transmitter. Group delay variations degrade the composite amplitude response, which in turn limits stereo separation. A properly designed, broadband grid matching network is essential for proper operation of the entire transmitter. Even if the output bandwidth were not limited, the grid circuit could seriously affect the transmitter's performance.

This degradation due to phase response is true for any tuned circuit, even if that stage is run into saturation. Therefore it makes sense to eliminate as many tuned stages as possible. This is why a wideband, solid state exciter and intermediate power amplifier (IPA) are advantageous in high power FM transmitters, even though the output stage uses a tube (1), (2).

WHY LIMIT BANDWIDTH?

If there were only one radio signal being transmitted at any given time, there would be no need to limit the bandwidth. However, any time two signals are present, there exists the possibility of RF intermodulation between them. All that is required is a non-linear device acting as a mixer, which creates two more intermodulation products. The transmitter final amplifier is that non-linear active device. If any other frequency finds its way back into the output stage, RF intermodulation will occur. This mixing will have some conversion loss, referred to as "turn-around-loss". There are three main contributors to the total turn-around-loss (5). They are:

1. The in-band conversion loss of the non-linear device.

2. The attenuation of the interfering signal due to the selectivity of the output stage.

3. The attenuation of the resulting IM products due to the selectivity of the output stage.

Notice that 2. and 3. relate to the transmitter output bandwidth. This clearly shows the desirability to have as much selectivity as possible in the output stage. This will be a design trade-off between system modulation performance and immunity from RF intermodulation. It is important to note that the broadband nature of a solid state broadcast transmitter makes its susceptibility to RF intermodulation greater than a tube/cavity output stage.

Broadcast engineers are faced with the following questions:

1. What is the optimum bandwidth for FM transmission?

2. At what point does the performance become acceptable?

3. What is the limit of diminishing returns where you pick up basically no more modulation performance, but continue to "open up the door" to increased RF intermodulation?

TESTING RF BANDWIDTH PERFORMANCE

How is the optimum bandwidth determined? There are models available (6),(7) to predict distortion performance, but these require that the transfer function of the network is known and assumed to be passive. It is practically impossible to model an FM broadcast transmitter operating class C, due to its nonlinear transfer function.

A straightforward empirical alternative is to measure the performance degradation of a "perfect" modulator when it is passed through a passive band limiting network. A real broadcast transmitter is not practical for this test, as there is only a very limited range of bandwidth variation available, and determining its true bandwidth is difficult due to grid saturation effects.

A test cavity was constructed to simulate the effects of band limiting. The tuning and loading range was sufficient to allow bandwidth testing from 400 kHz to 3 MHz (-3 dB). While the effects of the grid circuit were not seen, the output bandwidth effects were very accurately modeled. This was useful for several reasons. First, it showed the performance degradation caused by various bandwidth limitations. Second, it shows at what bandwidth performance ceased to improve. Third, it provides a good basis to compare to a real broadcast transmitter. Figure 1 shows the physical construction of this test cavity.

The resulting data gives a clearer insight into the effects of the grid circuit and the non-linear effects of the output tube, based on actual performance vs. measured bandwidth of a real transmitter. It also shows that 3 dB bandwidth is not necessarily a good measure of synchronous AM performance due to the more complex response of the entire transmitter design.

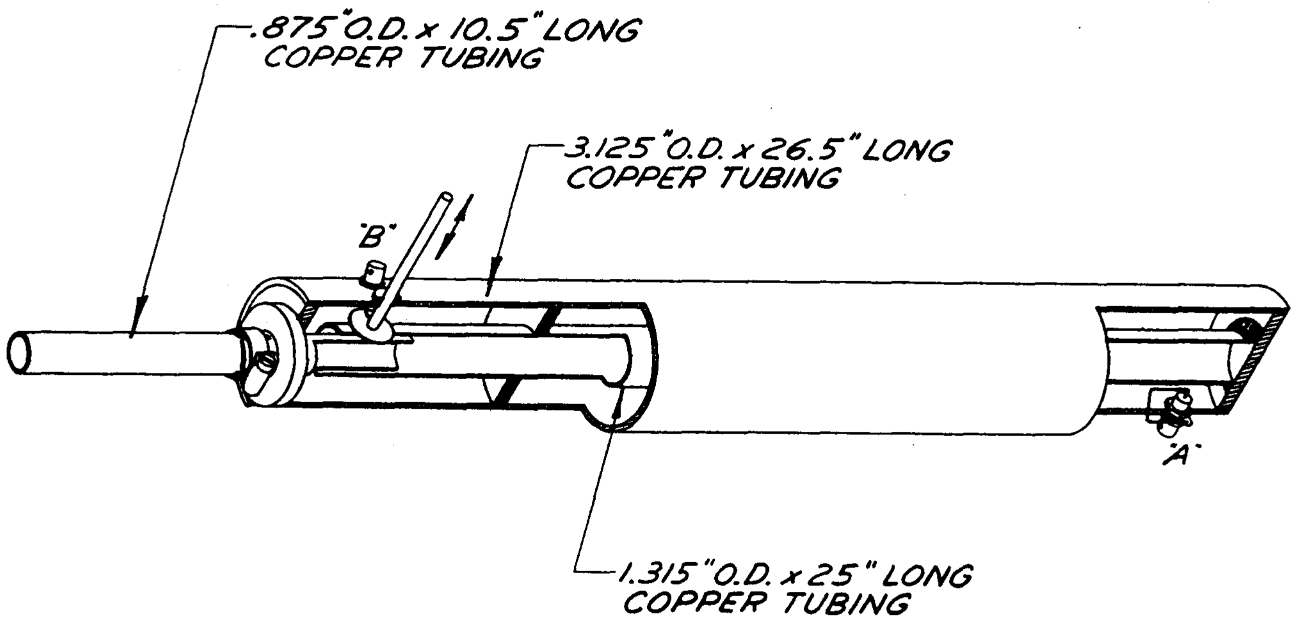


FIGURE 1. TEST CAVITY CONSTRUCTION

The Test Equipment

Before a determination of performance degradation can be made, a benchmark must exist to define the desired goal, or "perfect" FM modulation. In a wideband RF environment, the system performance is limited only by the FM exciter used (the modulator), and the receiver (demodulator). The accuracy of the test is limited by the distortion, noise, and composite amplitude response of this test equipment.

Figure 2 shows the performance of the Broadcast Electronics, Inc. model FX-50, 50 watt FM Exciter, measured with the Belar Electronics model FMM-2 FM Modulation Monitor and model FMS-2 FM Stereo Modulation Monitor. Audio generation and measurement was done with the Audio Precision System One audio test set. Stereo encoding was accomplished with the Broadcast Electronics model FS-30 FM Stereo Generator.

This combination provided a guaranteed signal to noise ratio of -90 dB minimum, THD+N, SMPTE and CCIF IMD performance better than 0.005%, composite amplitude response of better than ±0.025 dB, composite phase response of ±0.1 degree, and stereo separation of 60 dB, 30 Hz to 5 kHz, greater than 52 dB, 5 kHz to 15 kHz.

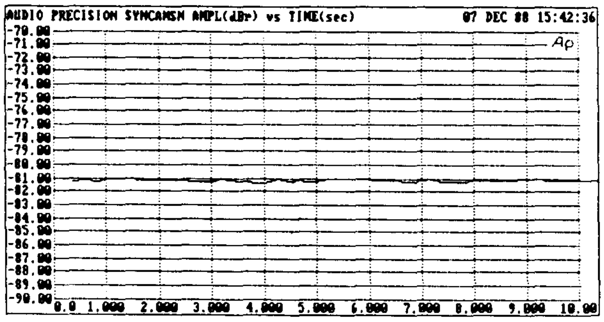
The Test Setup

Figure 3 shows the setup used to test the performance degradation of the FX-50 Exciter caused by various bandwidth restrictions. The Audio Precision System One test set was used to measure the audio performance. This allowed a very complete and consistent set of data to be compiled for each bandwidth test.

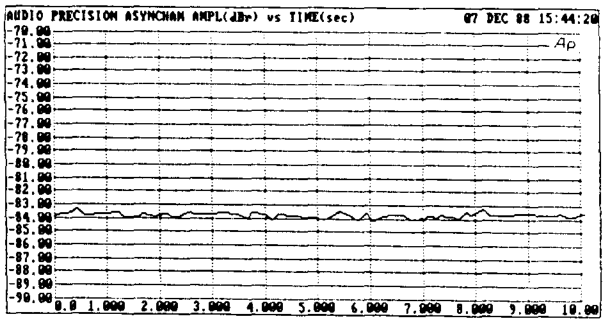
The System One audio oscillator fed either the FS-30 stereo generator for the stereo performance tests, or the FX-50 composite input directly for the baseband composite performance tests.

The output of the FX-50 was connected to the variable bandwidth test cavity. The cavity was adjusted for the desired -3 dB bandwidths of 400 kHz, 600 kHz, 800 kHz, 1 MHz, 1.5 MHz, 2 MHz, and 3 MHz. Figure 4 shows the amplitude and group delay responses of the test cavity at each setting.

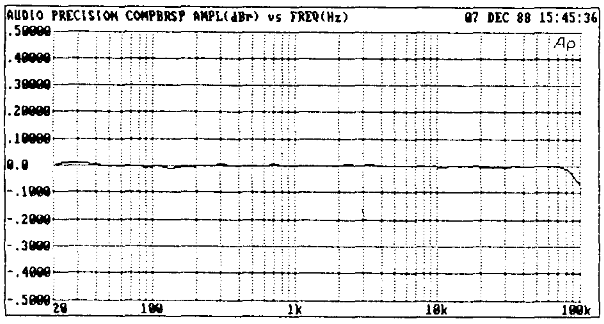
The cavity was loaded by a 50 ohm, 20 dB attenuator, and a sample was connected to the FMM-2. The de-emphasized audio and wideband composite outputs were used for the composite tests. The composite baseband was also used to drive the FMS-2, and the Tektronix model 7L5 spectrum analyzer. The decoded left and right outputs of the FMS-2 were used for the stereo performance tests.



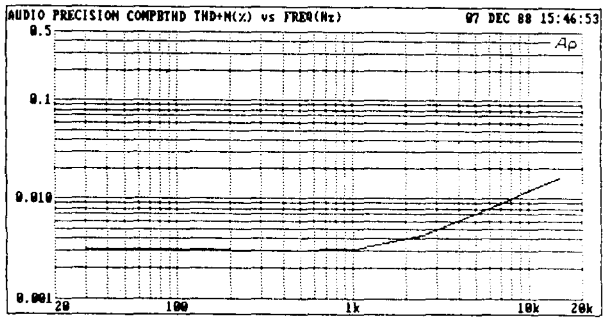
FX50 SYNCHRONOUS AM SIGNAL TO NOISE vs. TIME
10 SECOND SWEEP WITH 75uS DEEMPHASIS BELOW EQUIVALENT
100% AM MODULATION WITH +/-75KHz FM MODULATION AT 400Hz



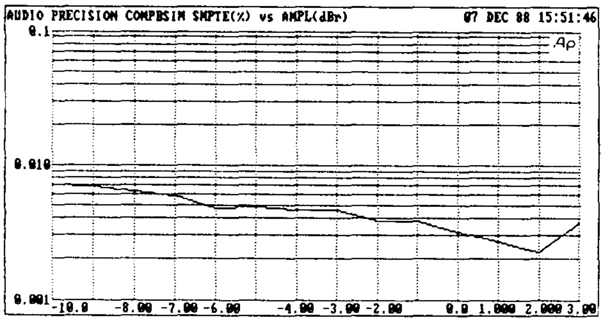
FX50 ASYNCHRONOUS AM SIGNAL TO NOISE vs. TIME
10 SECOND SWEEP WITH 75uS DEEMPHASIS BELOW EQUIVALENT
100% AM MODULATION



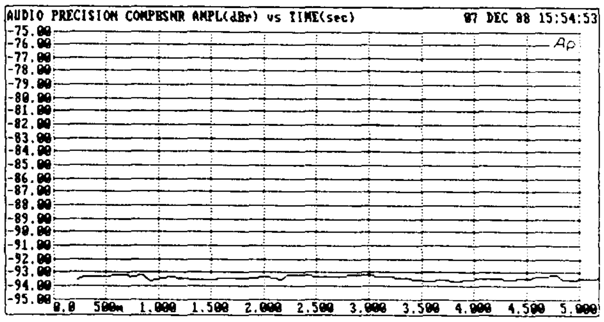
FX50 COMPOSITE FREQUENCY RESPONSE
20Hz TO 100KHz, GENERATOR/ANALYZER NORMALIZED
BELAR FMM-2 DEMODULATOR, STEREO OUTPUT



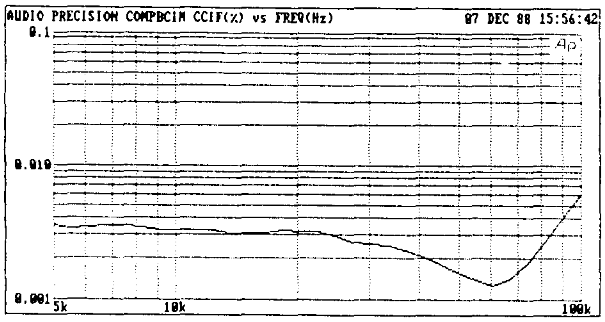
FX50 COMPOSITE THD+N vs. FREQUENCY
30 Hz TO 15 KHz, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, BALANCED OUTPUT



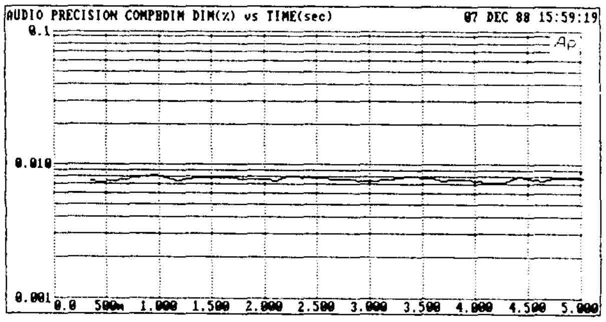
FX50 COMPOSITE SMPTE IMD vs. LEVEL
60Hz/7KHz, 1:1 RATIO FROM 3dB OVERMODULATION TO
-10dB UNDERMODULATION (0dBr = +/-75KHz)



FX50 COMPOSITE SIGNAL TO NOISE RATIO vs. TIME
5 SECOND SWEEP, BELAR FMM-2 DEMODULATOR,
75uS DEEMPHASIS, BALANCED OUTPUT

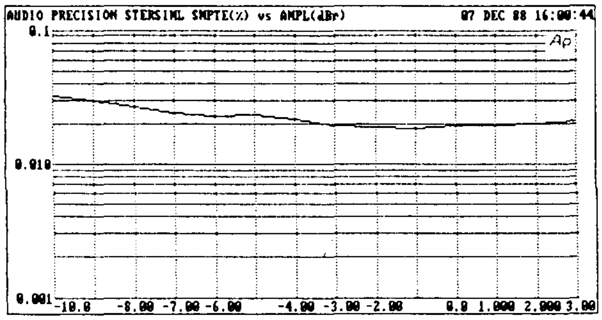


FX50 COMPOSITE CCIF IMD vs. FREQUENCY
TWIN TONE 1:1 RATIO FROM 99/100KHz TO 5/4KHz
AT +/- 75KHz DEVIATION, NO DEEMPHASIS

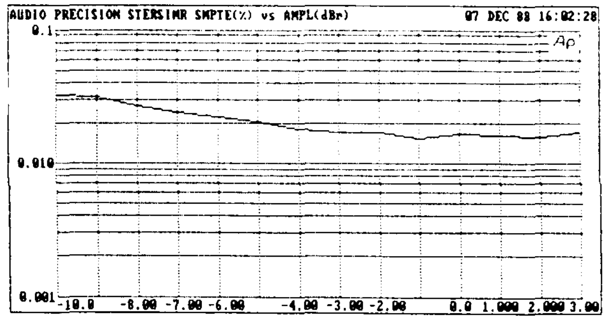


FX50 COMPOSITE DIM/TIM vs. TIME
5 SECOND SWEEP, 3.15KHz SQARE WAVE/ 15KHz SINE WAVE
NO PREEMPHASIS, NO DEEMPHASIS

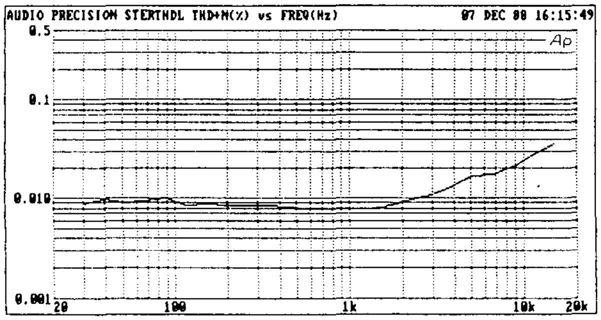
FIGURE 2. FX-50 FM EXCITER PERFORMANCE DATA
(Sheet 1 of 3)



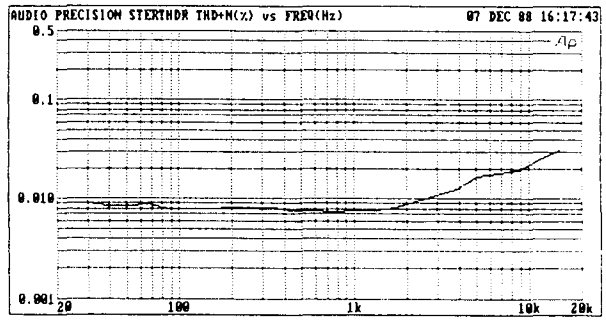
FX50/FS30 LEFT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)



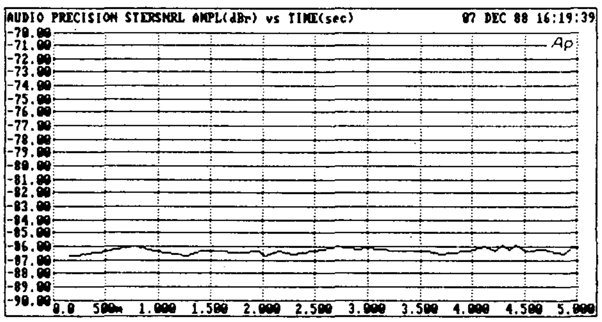
FX50/FS30 RIGHT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)



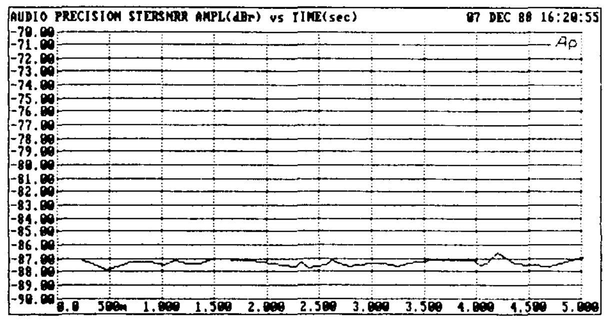
FX50/FS30 LEFT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER



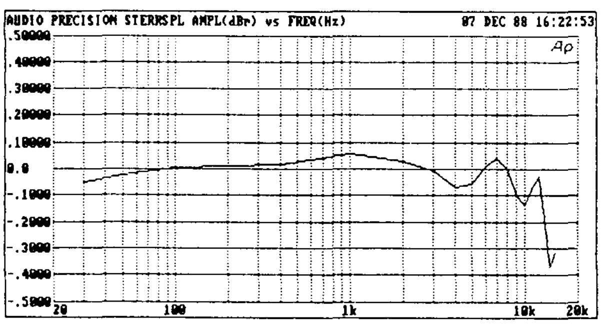
FX50/FS30 RIGHT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER



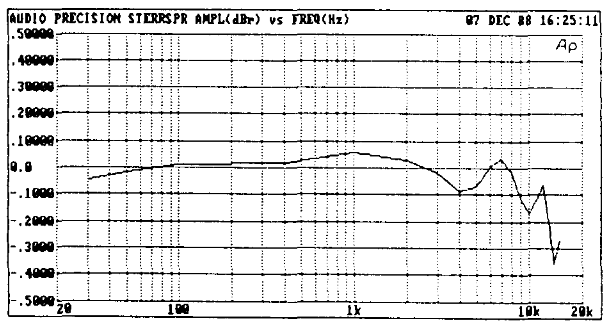
FX50/FS30 LEFT CHANNEL FM SIGNAL TO NOISE RATIO
5 SECOND SWEEP, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER



FX50/FS30 RIGHT CHANNEL FM SIGNAL TO NOISE RATIO
5 SECOND SWEEP, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

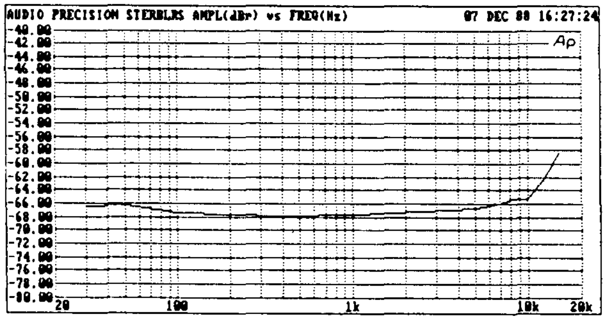


FX50/FS30 LEFT CHANNEL FREQUENCY RESPONSE
30Hz TO 15KHz, GENERATOR EQUALIZED FOR 75uS DEEMPHASIS

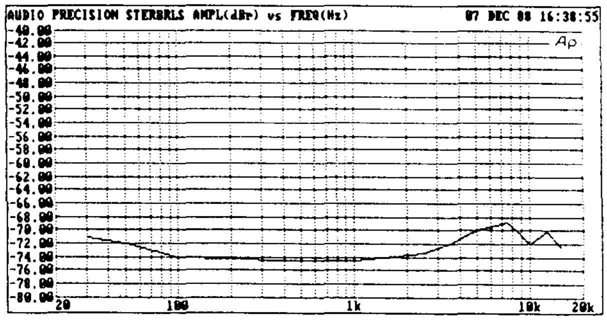


FX50/FS30 RIGHT CHANNEL FREQUENCY RESPONSE
30Hz TO 15KHz, GENERATOR EQUALIZED FOR 75uS DEEMPHASIS

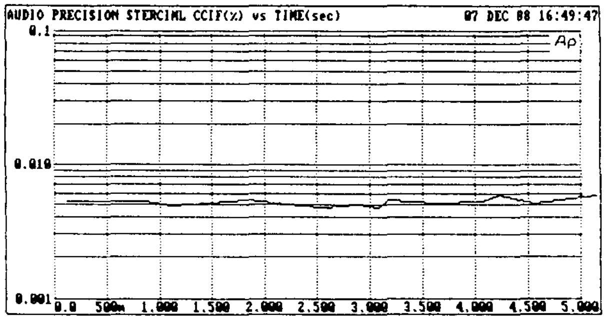
FIGURE 2. FX-50 FM EXCITER PERFORMANCE DATA
(Sheet 2 of 3)



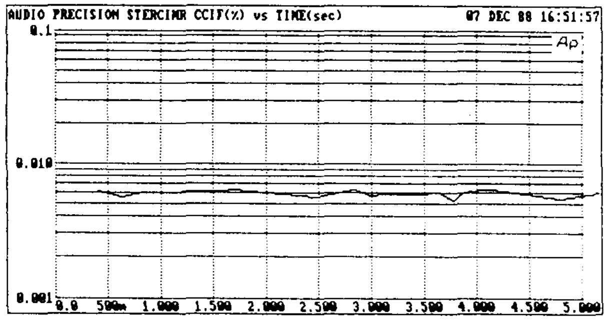
FX50/FS30 STEREO SEPARATATION, LEFT TO RIGHT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER
NO DE-EMPHASIS



FX50/FS30 TRANSMITTER STEREO SEPARATATION, RIGHT TO LEFT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER



FX50/FS30 LEFT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS



FX50/FS30 RIGHT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS

FIGURE 2. FX-50 FM EXCITER PERFORMANCE DATA
(Sheet 3 of 3)

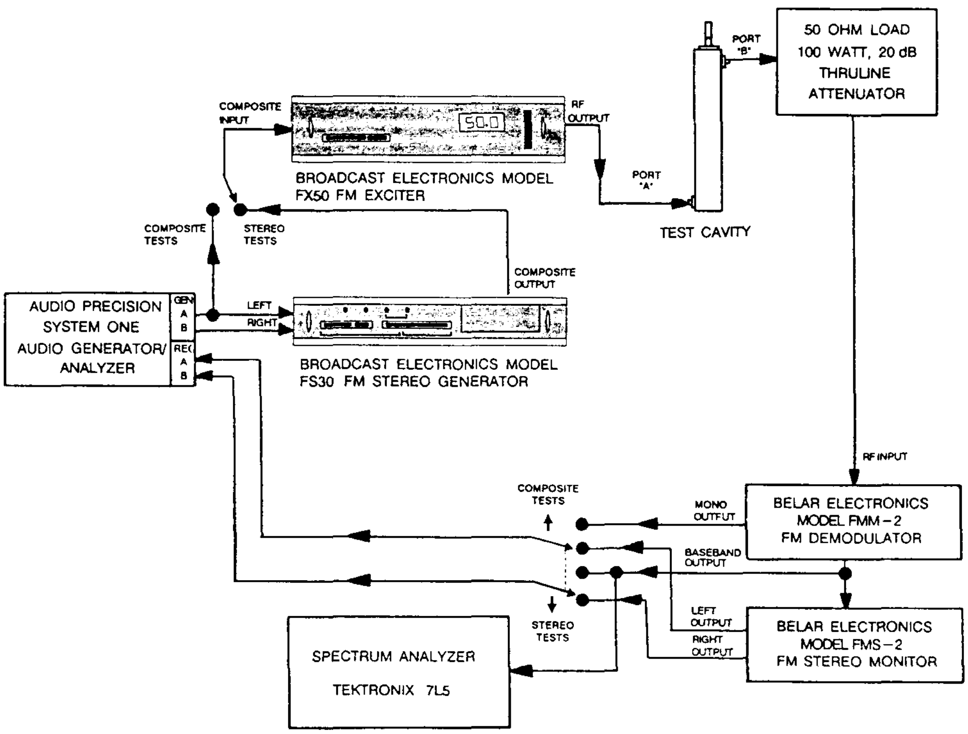


FIGURE 3. OPTIMUM BANDWIDTH TEST SETUP

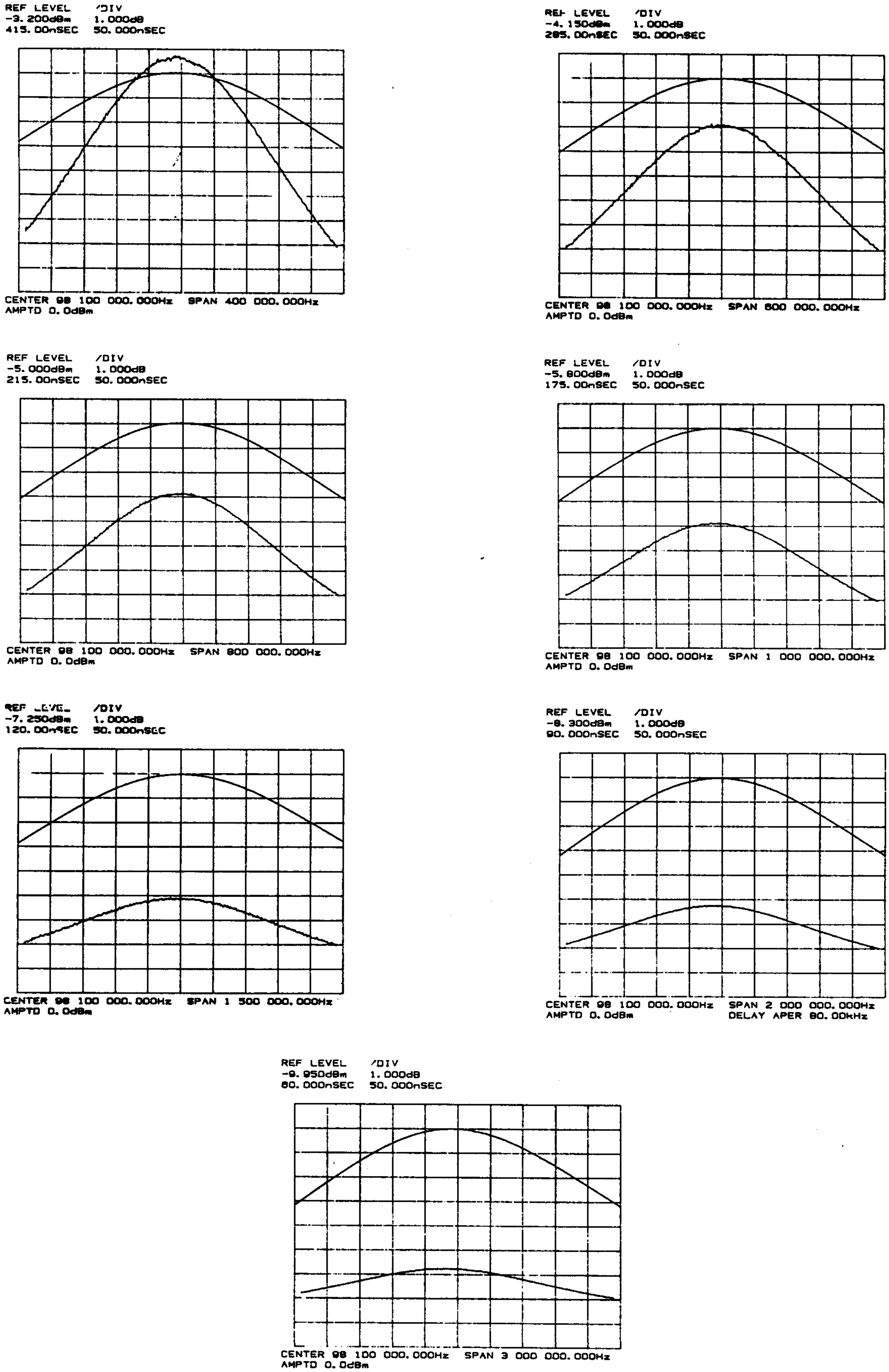


FIGURE 4. TEST CAVITY AMPLITUDE/GROUP DELAY SWEEPS vs. BANDWIDTH SETTING

PERFORMANCE DATA

Figure 5 - Synchronous AM

Figure 5 shows the synchronous AM performance of the test cavity, adjusted for the various bandwidths. Very close correlation between test results and computer modelling of predicted synchronous AM performance was obtained (3). This is because the band limiting network is completely passive, and can be accurately modeled.

Based on this data, better than 40 dB of synchronous AM should be achieved with only 800 kHz of RF bandwidth. This passive representation is only an approximate method of predicting synchronous AM performance.

Figure 6 - Asynchronous AM

Figure 6 confirms that there is no change in Asynchronous AM signal to noise ratio with bandwidth.

Figure 7 - Composite Frequency Response

A dramatic degradation in composite frequency response occurs below 600 kHz. Above 800 kHz to 1 MHz, very little improvement in response is seen. The effects of this parameter are more clearly illustrated by the stereo separation tests.

Figure 8 - Composite THD+N

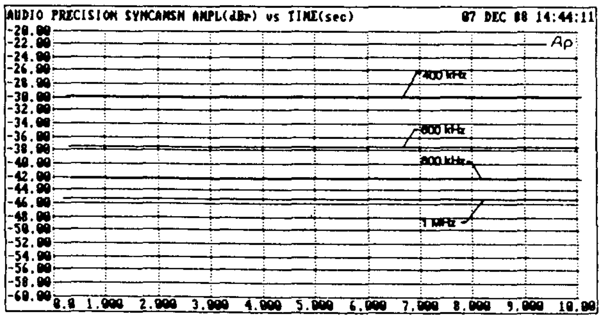
Figure 8 shows the rise in THD+N with frequency as the bandwidth is varied. With more than 600 KHz bandwidth, the THD+N is better than 0.1%, 30 Hz to 15 kHz.

There is virtually no improvement in performance above 1.5 MHz bandwidth, as shown in the second graph.

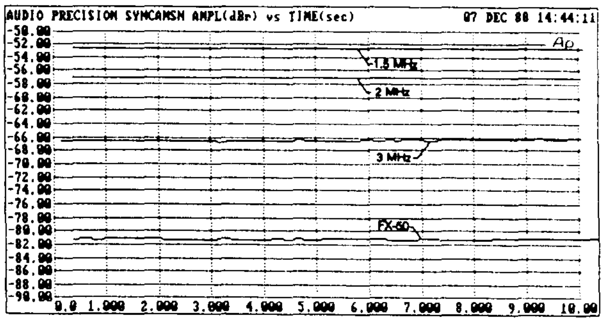
Figure 9 - Composite SMPTE IMD

Even at 400 kHz bandwidth, SMPTE IMD is better than 0.1% (measured at 0.05%), and crosses the 0.01% mark at 1 MHz RF bandwidth.

This test is actually SMPTE IMD vs. Level, which shows the IMD performance from 10 dB below 100% modulation to 3 dB above 100% modulation. SMPTE IMD is specified at 100% modulation (Ø dBr the horizontal axis of Figure 9A and 9B).

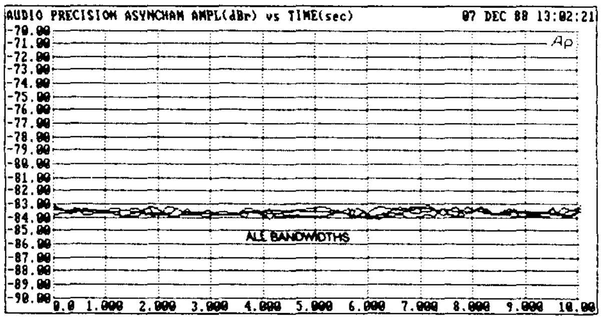


TRANSMITTER SYNCHRONOUS AM SIGNAL TO NOISE vs. TIME
10 SECOND SWEEP WITH 75uS DEEMPHASIS BELOW EQUIVALENT
100% AM MODULATION WITH +/-75KHz FM MODULATION AT 400Hz



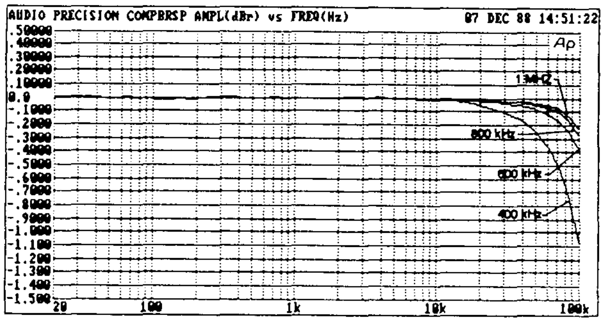
TRANSMITTER SYNCHRONOUS AM SIGNAL TO NOISE vs. TIME
10 SECOND SWEEP WITH 75uS DEEMPHASIS BELOW EQUIVALENT
100% AM MODULATION WITH +/-75KHz FM MODULATION AT 400Hz

FIGURE 5

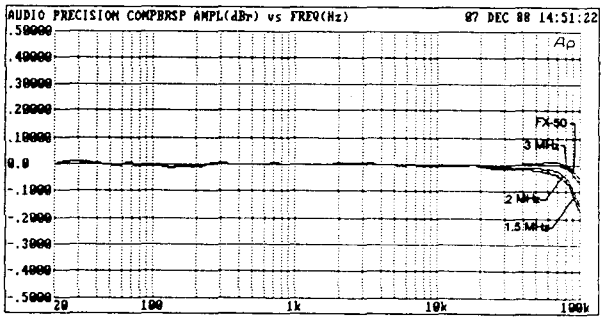


TRANSMITTER ASYNCHRONOUS AM SIGNAL TO NOISE vs. TIME
10 SECOND SWEEP WITH 75uS DEEMPHASIS BELOW EQUIVALENT
100% AM MODULATION

FIGURE 6

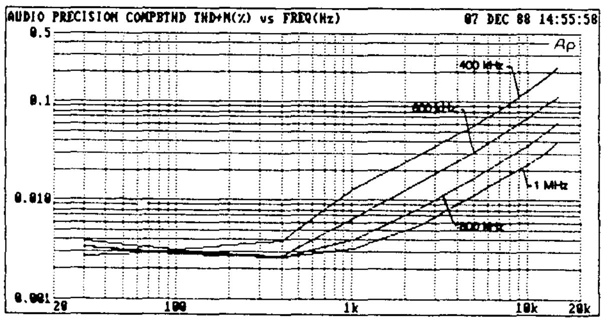


TRANSMITTER COMPOSITE FREQUENCY RESPONSE
20Hz TO 100KHz, GENERATOR/ANALYZER NORMALIZED
BELAR FMM-2 DEMODULATOR, STEREO OUTPUT

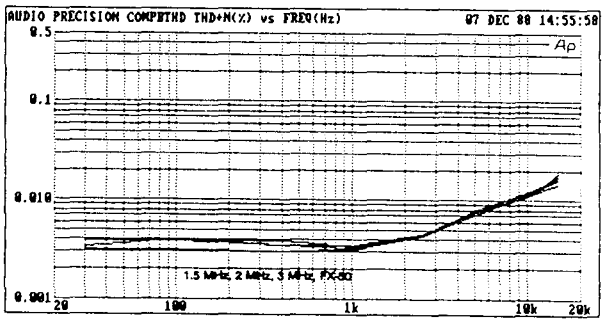


TRANSMITTER COMPOSITE FREQUENCY RESPONSE
20Hz TO 100KHz, GENERATOR/ANALYZER NORMALIZED
BELAR FMM-2 DEMODULATOR, STEREO OUTPUT

FIGURE 7

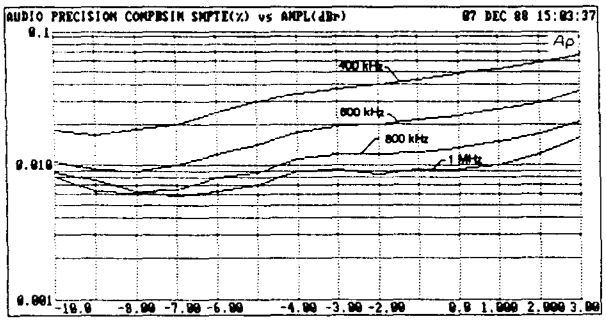


TRANSMITTER COMPOSITE THD+N vs. FREQUENCY
30 Hz TO 15 KHz, 75uS DEEMPHASIS
80 KHz AUDIO BANDWIDTH

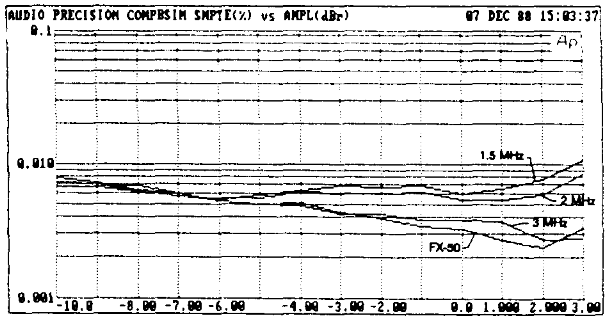


TRANSMITTER COMPOSITE THD+N vs. FREQUENCY
30 Hz TO 15 KHz, 75uS DEEMPHASIS
80 KHz AUDIO BANDWIDTH

FIGURE 8



TRANSMITTER COMPOSITE SMPTE IMD vs. LEVEL
60Hz/7KHz, 1:1 RATIO FROM 3dB OVERMODULATION TO
-10dB UNDERMODULATION (0dBr = +/-75KHz)

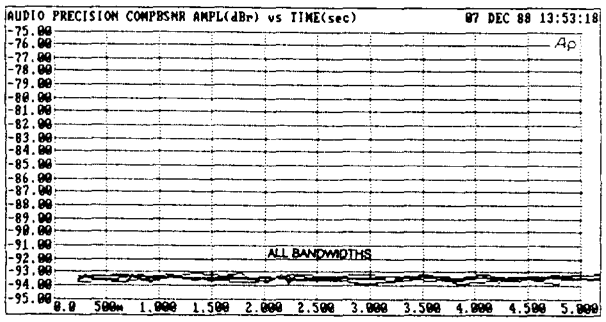


TRANSMITTER COMPOSITE SMPTE IMD vs. LEVEL
60Hz/7KHz, 1:1 RATIO FROM 3dB OVERMODULATION TO
-10dB UNDERMODULATION (0dBr = +/-75KHz)

FIGURE 9

Figure 10 - Composite FM Signal to Noise Ratio

As expected, no change in composite FM signal to noise ratio was observed as bandwidth was varied.



TRANSMITTER COMPOSITE SIGNAL TO NOISE RATIO vs. TIME
5 SECOND SWEEP, BELAR FMM-2 DEMODULATOR
75uS DEEMPHASIS, BALANCED OUTPUT

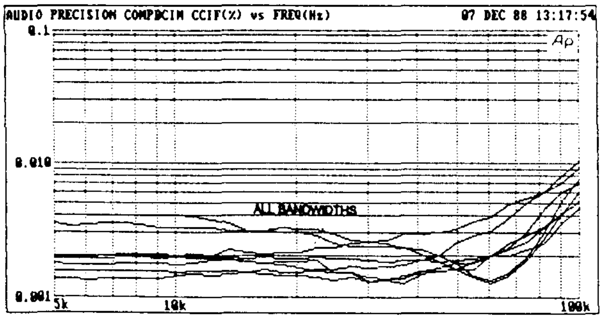
FIGURE 10

Figure 11 - Composite CCIF IMD

Surprising results were obtained during this test. Figure 11 shows little change in CCIF IMD performance as bandwidth is varied. Upon closer examination, it was found to be because the test tone is comprised of equal amplitude components, which keeps the individual modulation indexes low, thereby reducing the bandwidth required for low distortion.

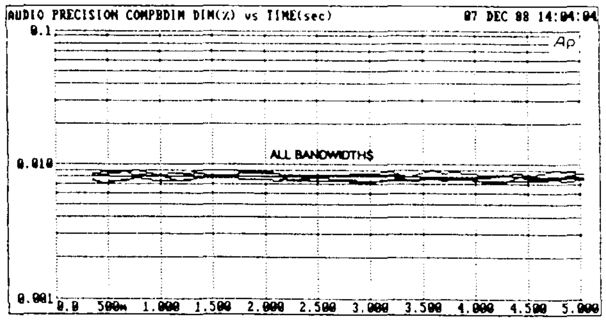
Figure 12 - Composite DIM/TIM

There is virtually no change in DIM/TIM performance vs. bandwidth. In fact, the FX50 measurement of 0.008% turns out to be noise limited. No IM products could be found by spectrum analysis.



TRANSMITTER COMPOSITE CCIF IMD vs. FREQUENCY
TWIN TONE 1:1 RATIO FROM 99/100 KHz TO 5/4 KHz
AT +/- 75 KHz DEVIATION, NO DEEMPHASIS

FIGURE 11

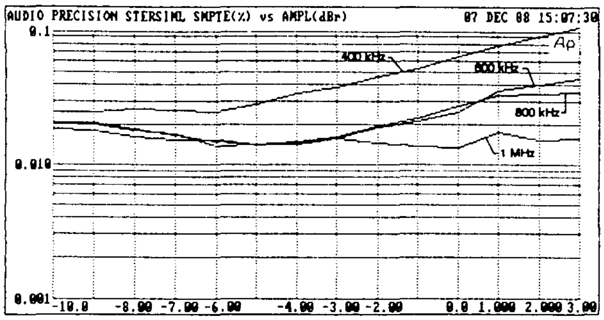


TRANSMITTER COMPOSITE DIM/TIM vs. TIME
5 SECOND SWEEP, 3.15 KHz SQUARE WAVE/ 15 KHz SINE WAVE
NO PREEMPHASIS, NO DEEMPHASIS

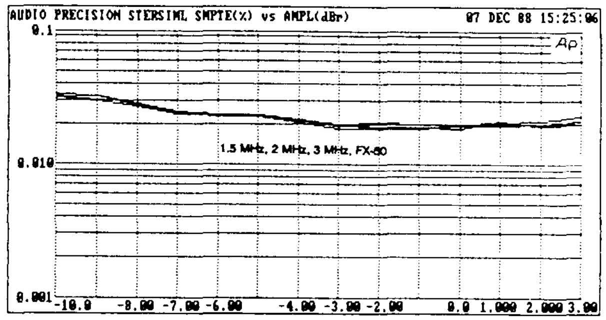
FIGURE 12

Figure 13 - Stereo SMPTE IMD

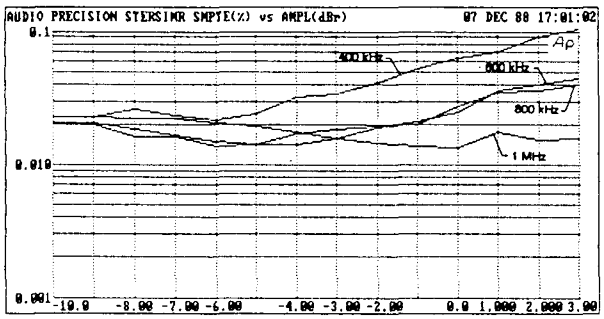
The stereo SMPTE IMD performance is better than 0.05% with 600 kHz or more bandwidth. Very little improvement is noticed above 1 MHz bandwidth.



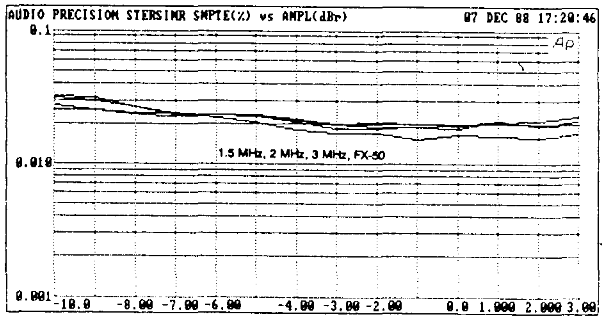
TRANSMITTER LEFT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)



TRANSMITTER LEFT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)



TRANSMITTER RIGHT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)



TRANSMITTER RIGHT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)

FIGURE 13

Figure 14 - Stereo THD+N

There is practically no improvement above 1 MHz bandwidth, with better than 0.1% performance, even at the 600 kHz mark.

Figure 15 - Stereo FM Signal to Noise Ratio

As expected, there was no change in stereo signal to noise ratio with bandwidth.

Figure 16 - Stereo Frequency Response

Stereo amplitude response is not effected with at least 400 kHz of RF bandwidth.

Figure 17 - Stereo Separation

This is an excellent example of the bandwidth effect on composite frequency response. At 400 kHz, separation is limited to slightly better than 40 dB, crossing the 50 dB performance mark at about 700 kHz bandwidth. Stereo separation reaches the 60 dB mark at about 1.5 MHz, and actually measures better at 3 MHz, left into right, than it does with the full bandwidth. This is due to the small errors adding in one channel while subtracting in the other.

Figure 18 - Stereo CCIF IMD

Excellent Stereo CCIF IMD performance was achieved with at least 600 kHz RF bandwidth.

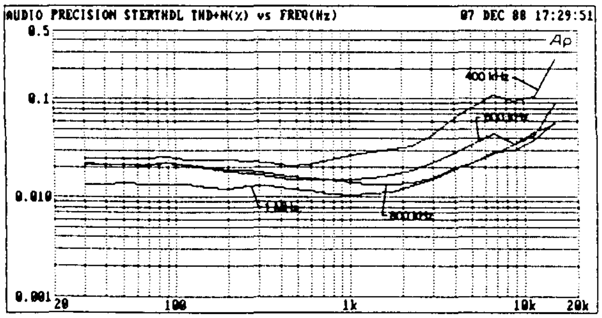
Figure 19 - Composite Baseband Spectrum Analysis

Spectrum analysis shows the distortion products generated with each bandwidth tested. The test was with 4.5 kHz single channel modulation. This produces several distortion products throughout the SCA frequency range. At 800 kHz bandwidth and above, all distortion products are more than 80 dB below 100% modulation.

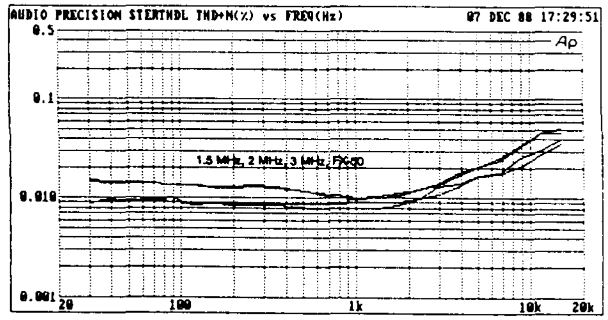
A REAL TRANSMITTER

Figure 20 shows the performance curves for the Broadcast Electronics model FM-20B. The data shown is representative of the entire "B" series of transmitters from Broadcast Electronics.

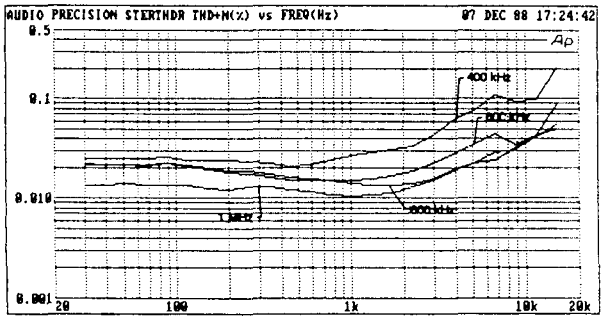
The FM-20B is a 20 KW broadcast transmitter using an Eimac 8989/ 4CX12,000A final tube in the patented folded half-wave cavity found in all Broadcast Electronics single tube transmitters.



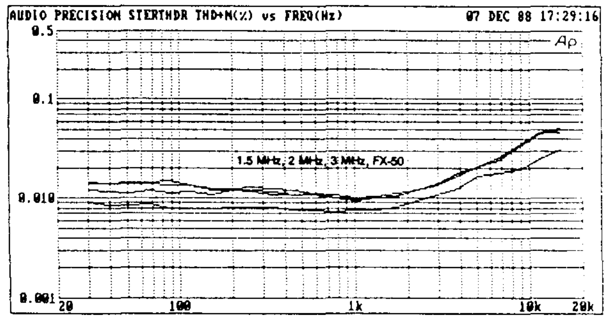
TRANSMITTER LEFT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER



TRANSMITTER LEFT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

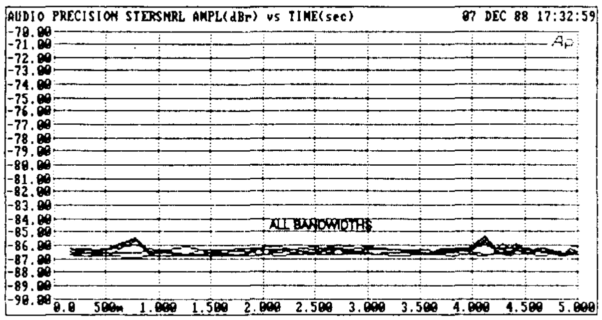


TRANSMITTER RIGHT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

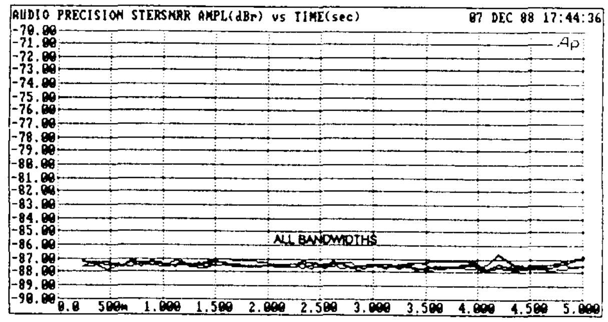


TRANSMITTER RIGHT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

FIGURE 14

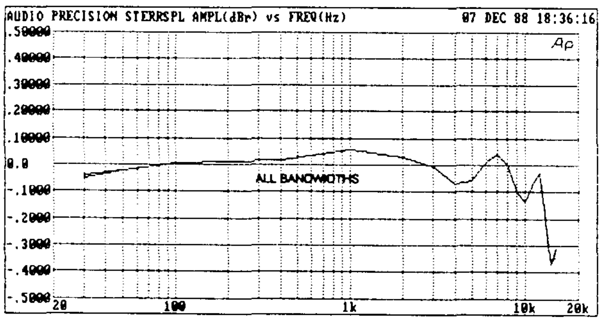


TRANSMITTER LEFT CHANNEL FM SIGNAL TO NOISE RATIO
5 SECOND SWEEP, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

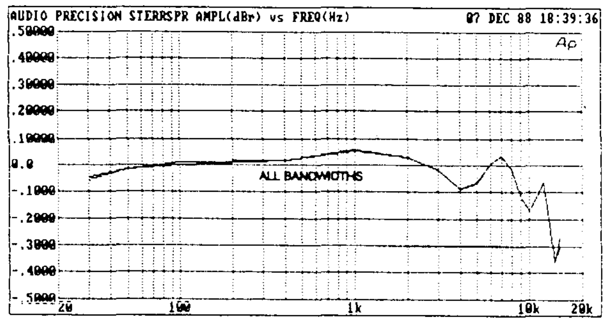


TRANSMITTER RIGHT CHANNEL FM SIGNAL TO NOISE RATIO
5 SECOND SWEEP, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

FIGURE 15

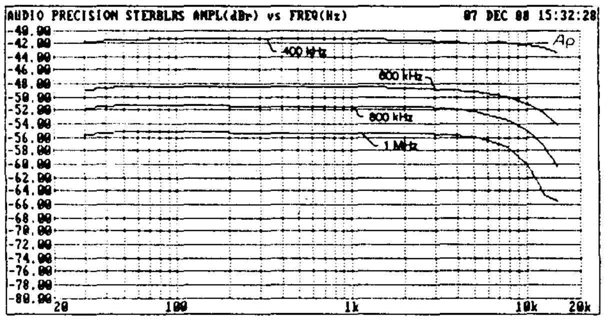


TRANSMITTER LEFT CHANNEL FREQUENCY RESPONSE
30Hz TO 15KHz, GENERATOR EQUALIZED FOR 75uS DEEMPHASIS

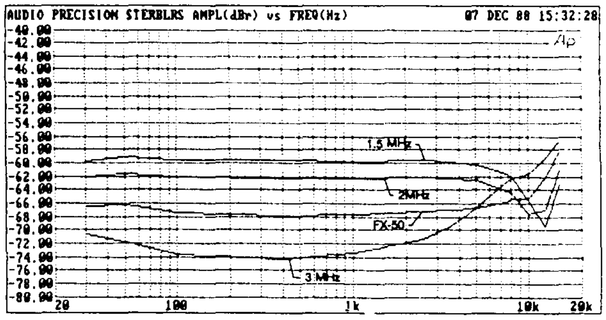


TRANSMITTER RIGHT CHANNEL FREQUENCY RESPONSE
30Hz TO 15KHz, GENERATOR EQUALIZED FOR 75uS DEEMPHASIS

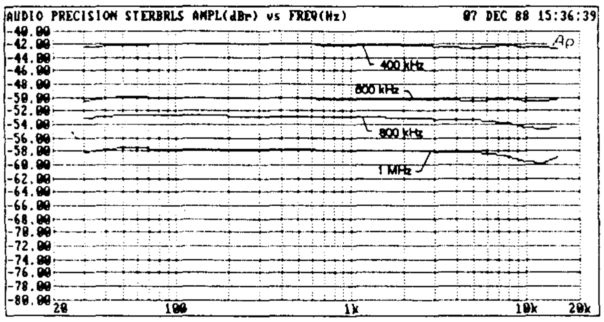
FIGURE 16



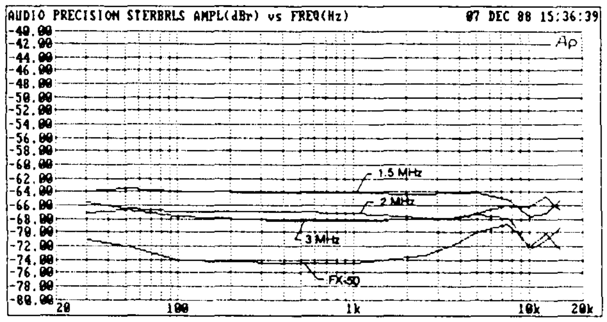
TRANSMITTER STEREO SEPARATATION, LEFT TO RIGHT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER
NO DE-EMPHASIS



TRANSMITTER STEREO SEPARATATION, LEFT TO RIGHT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER
NO DE-EMPHASIS

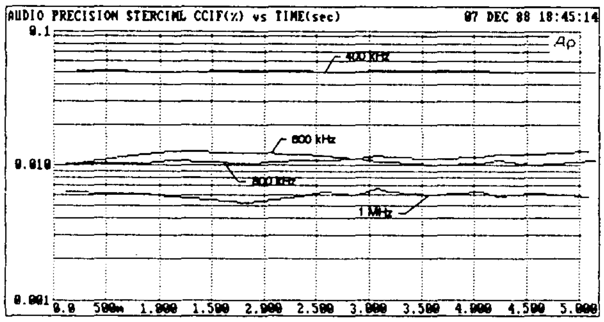


TRANSMITTER STEREO SEPARATATION, RIGHT TO LEFT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER
NO DE-EMPHASIS

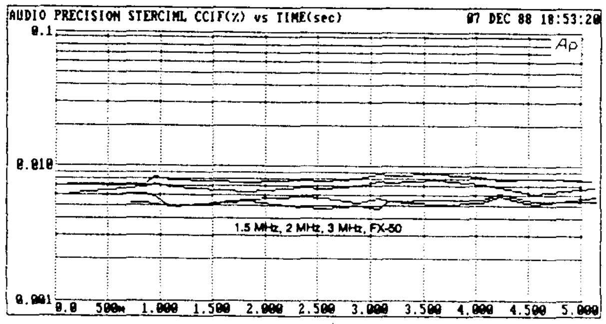


TRANSMITTER STEREO SEPARATATION, RIGHT TO LEFT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER
NO DE-EMPHASIS

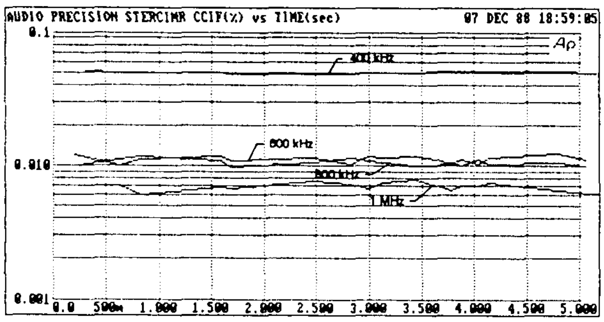
FIGURE 17



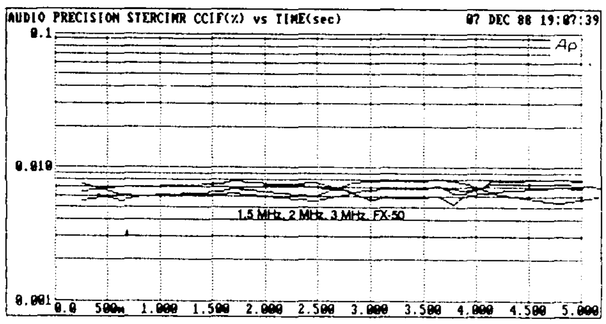
TRANSMITTER LEFT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS



TRANSMITTER LEFT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS

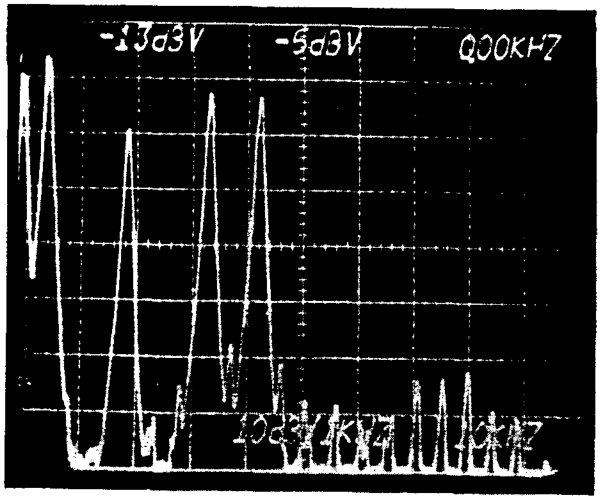


TRANSMITTER RIGHT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS

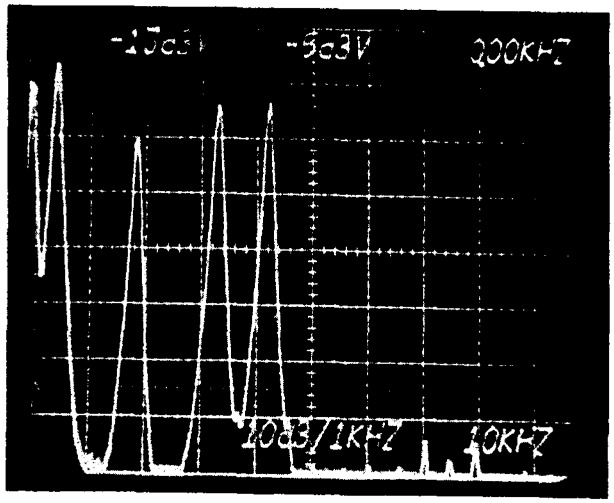


TRANSMITTER RIGHT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS

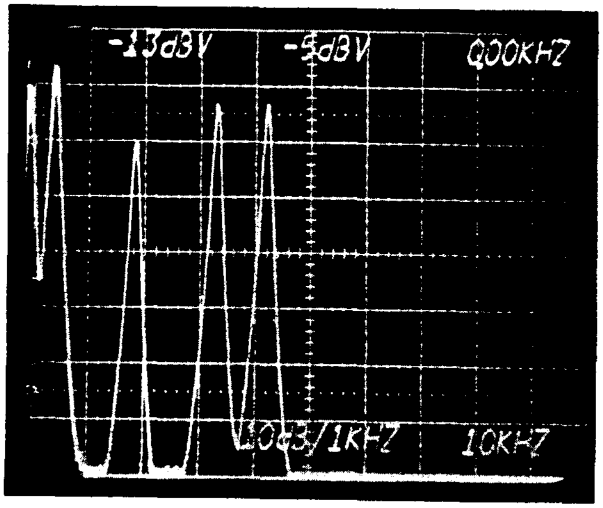
FIGURE 18



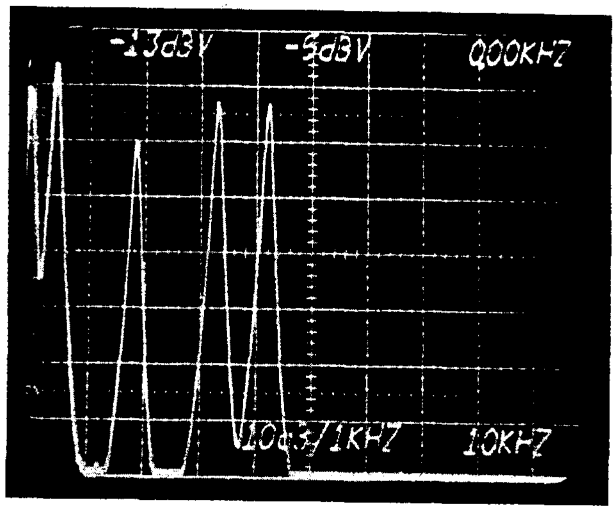
400 kHz



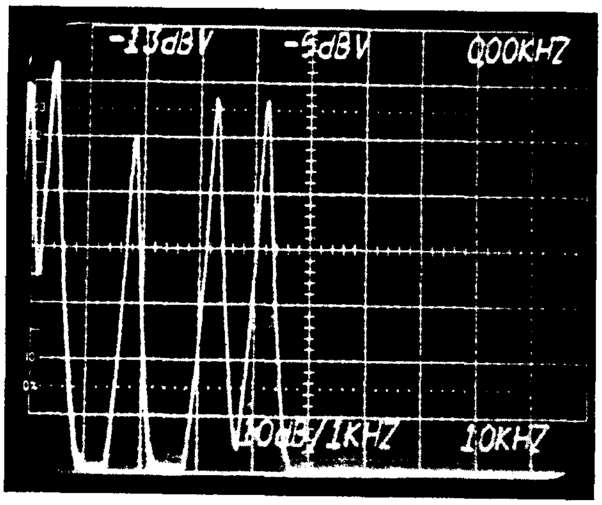
600 kHz



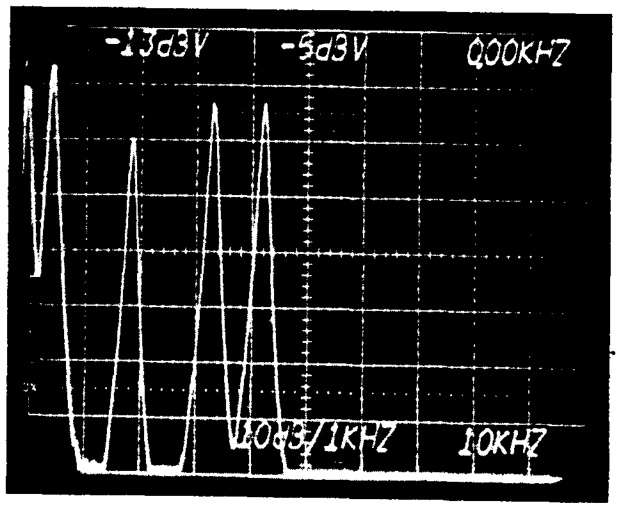
800 kHz



1 MHz



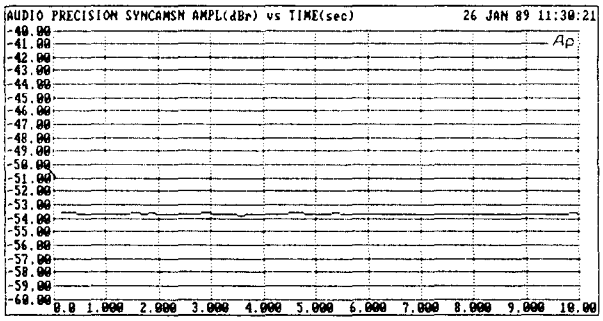
2 MHz



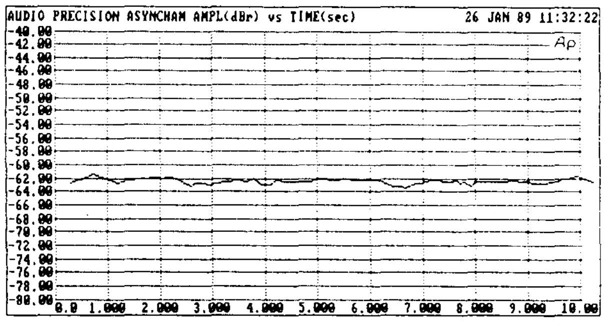
3 MHz

FIGURE 19. BASEBAND DISTORTION PRODUCTS vs. BANDWIDTH

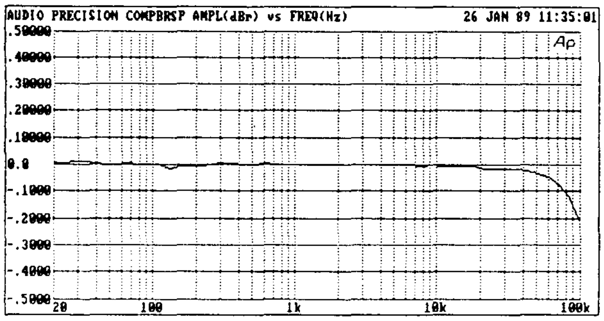
```
FM-20B OPTIMUM BANDWIDTH TEST, 101.1 MHz       THU 01/26/89    11:25:02AM
BROADCAST ELECTRONICS INCORPORATED    MODEL FM-20B     S/N 0000    VR2.2
--------------------------------------------------------------------------------
CONDITION: NORMAL OPERATION
--------------------------------------------------------------------------------
POWER AMPLIFIER (PA)    EFFICIENCY= 82%   | TRANSMITTER POWER OUTPUT
                                          |
                  PLATE    SCREEN    GRID | AUTHORIZED 20.00KW=100%       0.0KW ERP
VOLTAGE          9.66KV     667V    -302V | ACTUAL     20.00KW=100%       0.0KW ERP
CURRENT          2.51A      86MA     38MA |
POWER OUTPUT    20.00KW                   | REFLECTED   0.00KW=  0%
DISSIPATION      4.24KW      57W          | VSWR        1.0:1
--------------------------------------------------------------------------------
INTERMEDIATE POWER AMPLIFIER (IPA)        |
                     -1-        -2-       |
VOLTAGE             27.9V      27.7V      |
CURRENT             10.9A      11.2A      |
FORWARD POWER        203W       202W      |
REFLECTED POWER        2W         1W      |
DISSIPATION          101W       108W      |
TOTAL POWER       FWD= 364W   RFL=   3W   |                      *TOWER LITES*
------------------------------------------| EXHAUST AIR TEMP=  47 C
EXCITER FORWARD POWER       38W           |                  REMOTE CONTROL ON
EXCITER REFLECTED POWER      1W           | MPU CONTROL
```



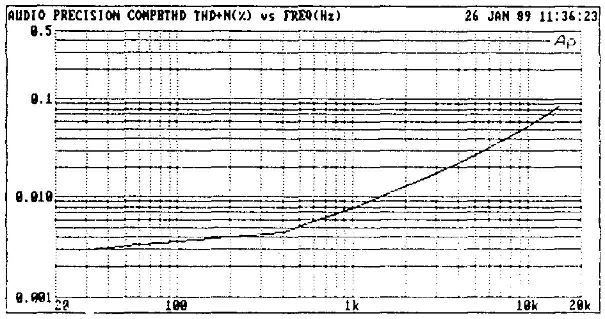
FM-20B SYNCHRONOUS AM SIGNAL TO NOISE vs. TIME
10 SECOND SWEEP WITH 75uS DEEMPHASIS BELOW EQUIVALENT
100% AM MODULATION WITH +/-75KHz FM MODULATION AT 400Hz



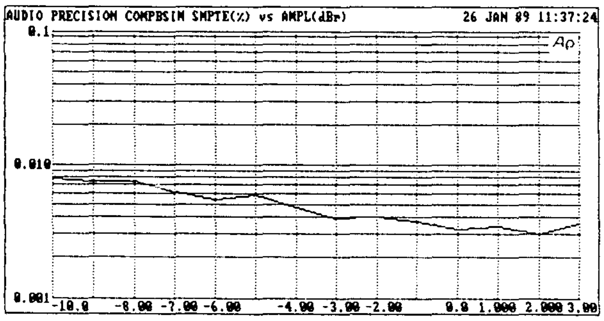
FM-20B ASYNCHRONOUS AM SIGNAL TO NOISE vs. TIME
10 SECOND SWEEP WITH 75uS DEEMPHASIS BELOW EQUIVALENT
100% AM MODULATION



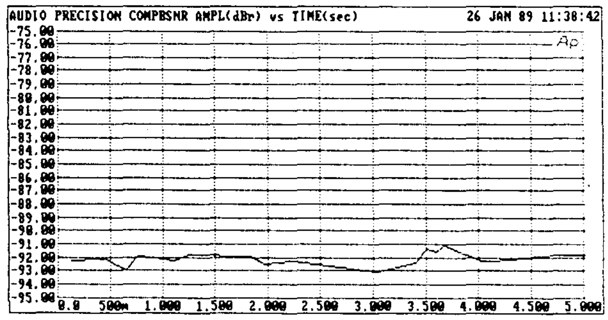
FM-20B COMPOSITE FREQUENCY RESPONSE
20Hz TO 100KHz, GENERATOR/ANALYZER NORMALIZED
BELAR FMM-2 DEMODULATOR, STEREO OUTPUT



FM-20B COMPOSITE THD+N vs. FREQUENCY
30 Hz TO 15 KHz, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, BALANCED OUTPUT

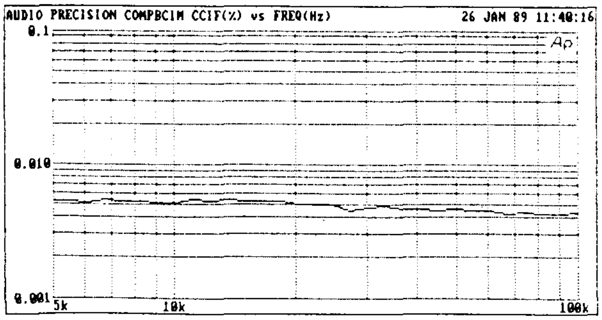


FM-20B COMPOSITE SMPTE IMD vs. LEVEL
60Hz/7KHz, 1:1 RATIO FROM 3dB OVERMODULATION TO
-10dB UNDERMODULATION (0dBr = +/-75KHz)

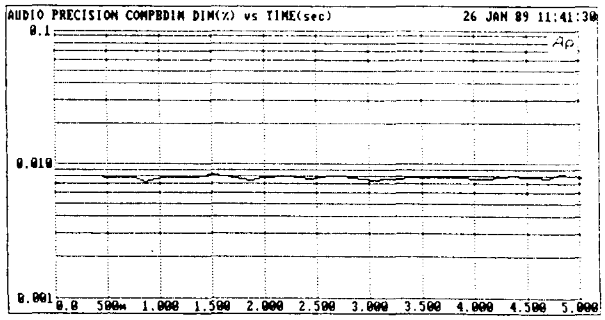


FM-20B COMPOSITE SIGNAL TO NOISE RATIO vs. TIME
5 SECOND SWEEP, BELAR FMM-2 DEMODULATOR,
75uS DEEMPHASIS, BALANCED OUTPUT

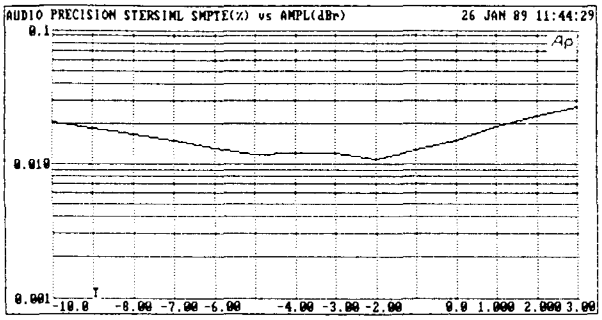
FIGURE 20. FM-20B 20kW TRANSMITTER PERFORMANCE DATA
(Sheet 1 of 3)



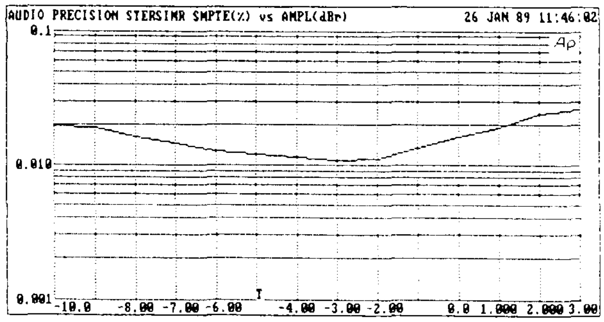
FM-20B COMPOSITE CCIF IMD vs. FREQUENCY
TWIN TONE 1:1 RATIO FROM 99/100KHz TO 5/4KHz
AT +/- 75KHz DEVIATION, NO DEEMPHASIS



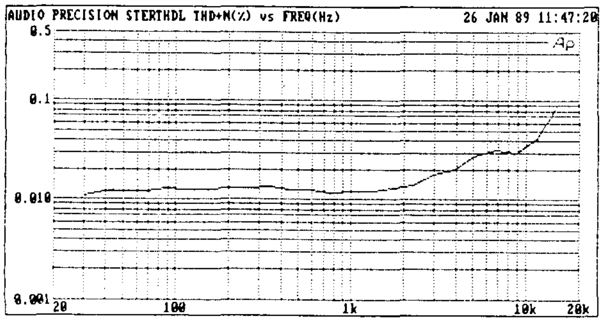
FM-20B COMPOSITE DIM/TIM vs. TIME
5 SECOND SWEEP, 3.15KHz SQARE WAVE/ 15KHz SINE WAVE
NO PREEMPHASIS, NO DEEMPHASIS



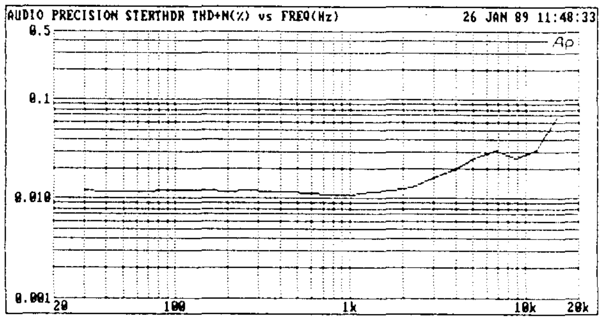
FM-20B LEFT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)



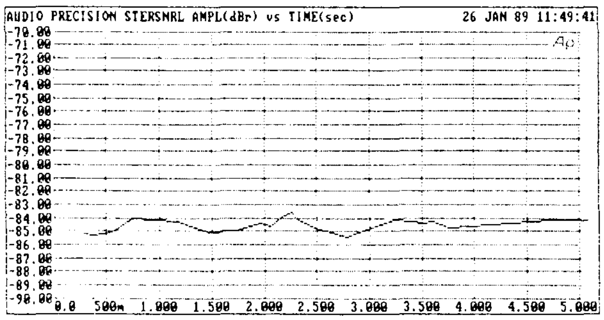
FM-20B RIGHT CHANNEL SMPTE IMD vs. LEVEL
60Hz/7KHz, 4:1 RATIO 75uS PREEMPHASIS, DEEMPHASIS
FROM 3dB OVERMODULATION TO -10dB BELOW 100% (0dB=100%)



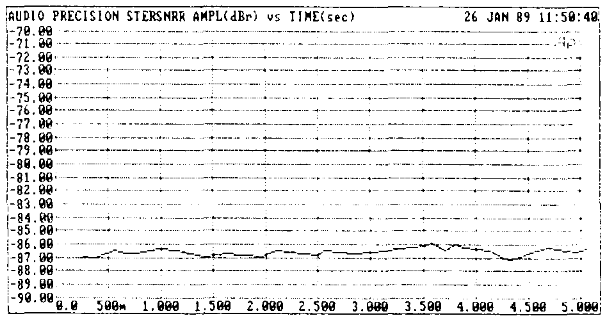
FM-20B LEFT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER



FM-20B RIGHT CHANNEL THD+N vs. FREQUENCY
30Hz TO 15KHz, 75uS PREEMPHASIS/DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

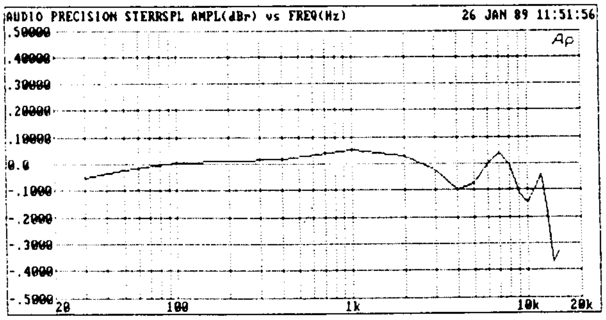


FM-20B LEFT CHANNEL FM SIGNAL TO NOISE RATIO
5 SECOND SWEEP, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

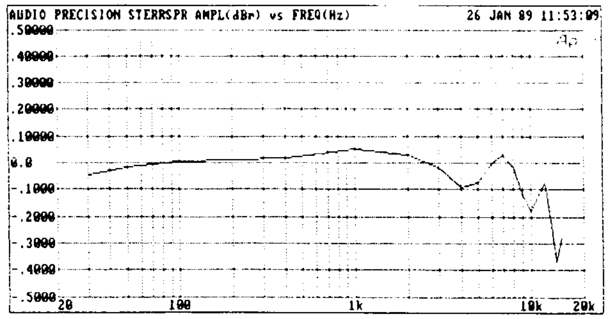


FM-20B RIGHT CHANNEL FM SIGNAL TO NOISE RATIO
5 SECOND SWEEP, 75uS DEEMPHASIS
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER

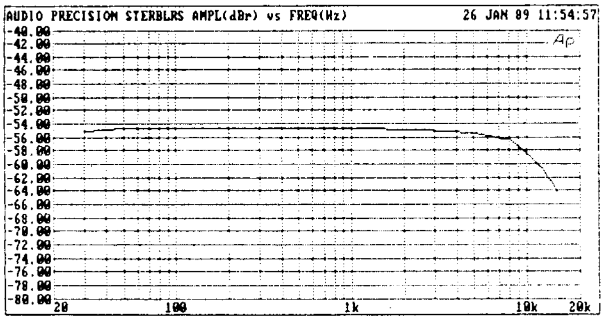
FIGURE 20. FM-20B 20kW TRANSMITTER PERFORMANCE DATA
(Sheet 2 of 3)



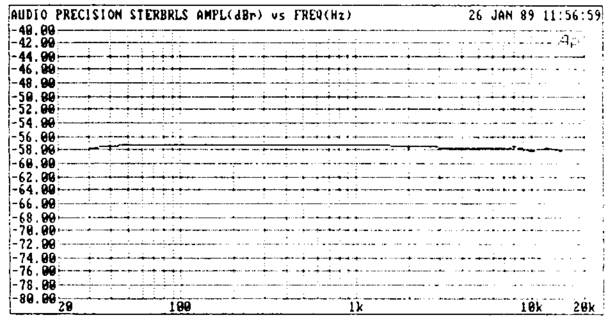
FM-20B LEFT CHANNEL FREQUENCY RESPONSE
30Hz TO 15kHz, GENERATOR EQUALIZED FOR 75uS DEEMPHASIS



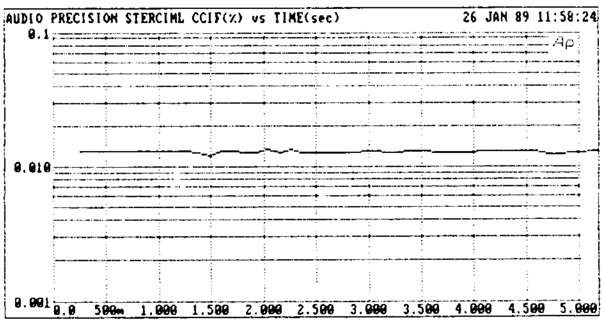
FM-20B RIGHT CHANNEL FREQUENCY RESPONSE
30Hz TO 15kHz, GENERATOR EQUALIZED FOR 75uS DEEMPHASIS



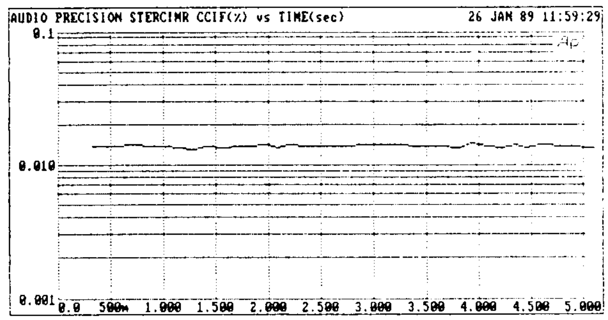
FM-20B STEREO SEPARATATION, LEFT TO RIGHT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER
NO DE-EMPHASIS



FM-20B STEREO SEPARATATION, RIGHT TO LEFT
BELAR FMM-2 DEMODULATOR, FMS-2 STEREO DECODER
NO DE-EMPHASIS



FM-20B LEFT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS

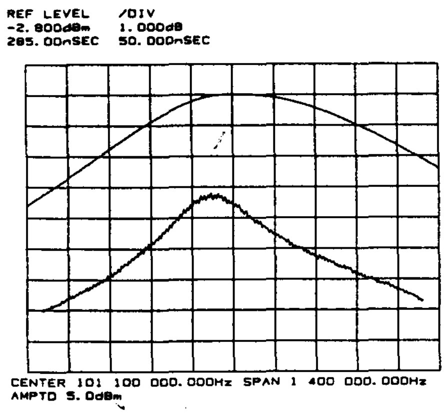


FM-20B RIGHT CHANNEL CCIF IMD vs. TIME
5 SECOND SWEEP, TWIN TONE 15KHz/14KHz 1:1
75uS PREEMPHASIS, NO DEEMPHASIS

FIGURE 20. FM-20B 20kW TRANSMITTER PERFORMANCE DATA
(Sheet 3 of 3)

The FM-20B also uses a patented broadband grid matching network to minimize the signal degradation caused by the grid circuit.

Figure 21 shows the actual measured bandwidth of the FM-20B. Notice that with the transmitter properly tuned for minimum synchronous AM, there is about a 1 dB difference between the upper and lower sidebands at ±700 KHz, respectively. This is perfectly normal and is due to the nature of a bandpass filter, which is symmetrical at the geometric upper and lower frequencies. In other words, the attenuation below center frequency is the mirror of the attenuation above center frequency when plotted on a logarithmic frequency axis, not a linear axis (11).



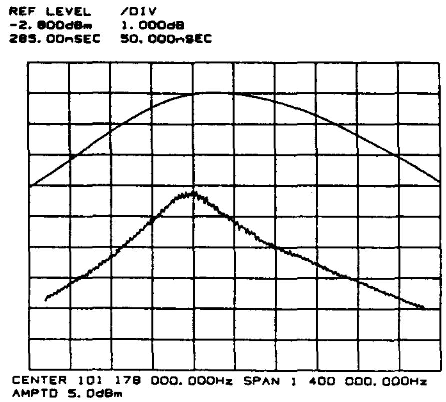


FIGURE 21

The second plot shows where the ±700 KHz points are symmetrical (-3 dB). The arithmetic mean (linear axis) center frequency is 78 KHz higher than the actual tuned frequency of the transmitter, but does show the 3 dB bandwidth to be 1.4 MHz.

The measured bandwidth and audio performance of the FM-20B do not exactly match the predictions based entirely on the passive band limiting tests, as expected. Slight variation is due to the non-linear input and output characteristics (transfer function) inherent to a class C tube power amplifier and matching networks.

The audio performance is excellent, with THD+N better than 0.01% at 400 Hz, with less than 0.1% at 15 kHz, SMPTE IMD better than 0.01%, greater than 54 dB stereo separation, and 92 dB signal-to-noise ratio, all with a -3 dB bandwidth of less than 1.5 MHz.

Also, as stated earlier, the synchronous AM performance is better than would be predicted from the measured 3 dB bandwidth.

CONCLUSIONS

The accurate prediction of actual audio performance from measured RF bandwidth is a difficult task due to the masking effects of the grid circuit and non-linear nature of the output stage in a single tube transmitter. Carefully controlled testing of RF bandwidth limitation by a passive network tends to show acceptable performance with as little as 800 kHz bandwidth, and little, if any, improvement with more than 1.5 MHz bandwidth.

This premise is verified by actual tests on a typical, real world FM broadcast transmitter of less than 1.5 MHz bandwidth.

Therefore, it is concluded that good audio performance can be achieved with as little as 800 kHz bandwidth, and that with 1.0 to 1.5 MHz bandwidth, excellent audio performance results are obtained, gaining only slight improvement above 1.5 MHz. This optimum bandwidth will produce outstanding audio fidelity with maximum protection from RF intermodulation potential.

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He is a member of the Phi Kappa Phi honor society and the National Radio Systems Committee (NRSC) FM Subgroup.

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