A Study OF RF INTERMODULATION BETWEEN TRANSMITTERS SHARING FILTERPLEXED OR CO-LOCATED ANTENNA SYSTEMS.

GEOFFREY N. MENDENHALL, P.E.
PRESIDENT, ENGINEERING
BROADCAST ELECTRONICS, INC.
QUINCY, ILLINOIS

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Interference to other stations within the FM broadcast band as well as to other services outside the broadcast band can be caused by RF intermodulation between two or more FM broadcast transmitters. This phenomenon has been well documented over the years, but detailed information on the susceptibility of various types of transmitters to interference from other co-located transmitters has not been thoroughly investigated.

The degree of intermodulation interference generated within a given system can be accurately predicted before the system is built, if the actual mixing loss of the transmitters is available when the system is designed. Accurate data on "Mixing Loss" or "Turn-Around-Loss" should not only speed the design of filterplexing equipment, but also result in higher performance and more cost effective designs because the exact degree of isolation required will be known before the system design phase is begun.

This paper describes a method by which the mixing loss between two FM transmitters can be accurately characterized. Manufacturers of transmitters can then supply this data to consultants and designers of filterplexed FM systems. Filterplexer characteristics, as well as antenna isolation requirements, can be tailored to the specific requirements of the transmitters being used. The end user can rest assured in advance of construction that the system will perform to specification without fear of overdesign or underdesign of the components within the system.

I. THE MECHANISMS WHICH GENERATE RF INTERMODULATION PRODUCTS

When two or more transmitters are coupled to each other, new spectral components are produced by mixing of the fundamental and harmonic terms of each of the desired output frequencies. For example, if only two transmitters are involved, the third order intermodulation terms could be generated in the following way. The output of the first transmitter (f1) is coupled into the non-linear output stage of the second transmitter (f2) because there is not complete isolation between the two output stages. (f1) will mix with the second harmonic of (f2) producing an in-band 3rd order term with a frequency of [2(f2)-(fl)]. in a similar fashion the other 3rd order term will be produced at a frequency of (2(fl)-(f2)]. This implies that the second harmonic content within each transmitter's output stage along with the specific non-linear characteristics of the output stage will have an effect on the value of the @mixing loss.

It is possible however to generate these same 3rd order terms in another way. If the difference frequency between the two transmitters [(f2)-(fl)] which is an out-of-band frequency, re-mixes with either (fl) or (f2), the same 3rd order intermodulation frequencies are produced.

Laboratory measurements indicate that the [2(f2)-(fl)] type of mechanism is the dominant mode generating 3rd order IM products in modern transmitters using a tuned cavity for the output network.

Figure 1 shows an example of how the intermodulation product frequencies may be calculated. Figures 2 & 3 show the resulting frequency spectra.

FIGURE 1
3RD ORDER INTERMODULATION PRODUCTS

f1 = 100.3 MHz.   f2 = 101.1 MHz.

2f1-f2 = [2(100.3)-(101.1)] = [200.6-101.1] = 99.5 MHz.

2f2-f1 = [2(101.1)-(100.3)] = [202.2-100.3] = 101.9 MHz.

OR

[f1-(f2-f1)] = [100.3-(101.1-100.3)] = [100.3-0.8] = 99.5 MHz.

[f2+(f2-f1)] = [101.1+(101.1-100.3)] = [101.1+0.8] = 101.9 MHz.

FIGURE 2

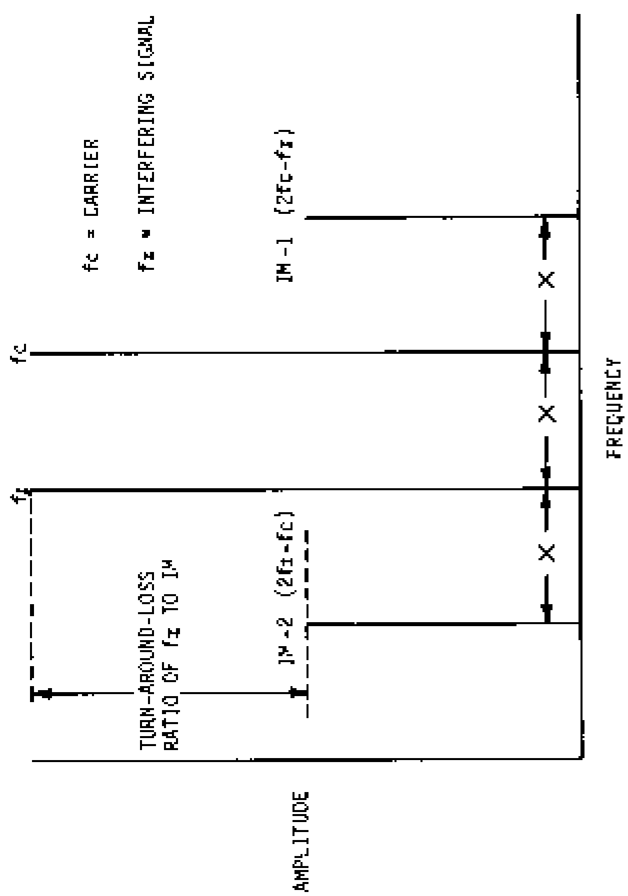


FIGURE 2
FREQUENCY SPECTRUM OF THIRD ORDER IM
WITH THE INTERFERING LEVEL EQUAL TO THE
CARRIER LEVEL

FIGURE 3

TYPICAL FREQUENCY SPECTRUM OF THIRD ORDER IM OF A BROADCAST FM TRANSMITTER

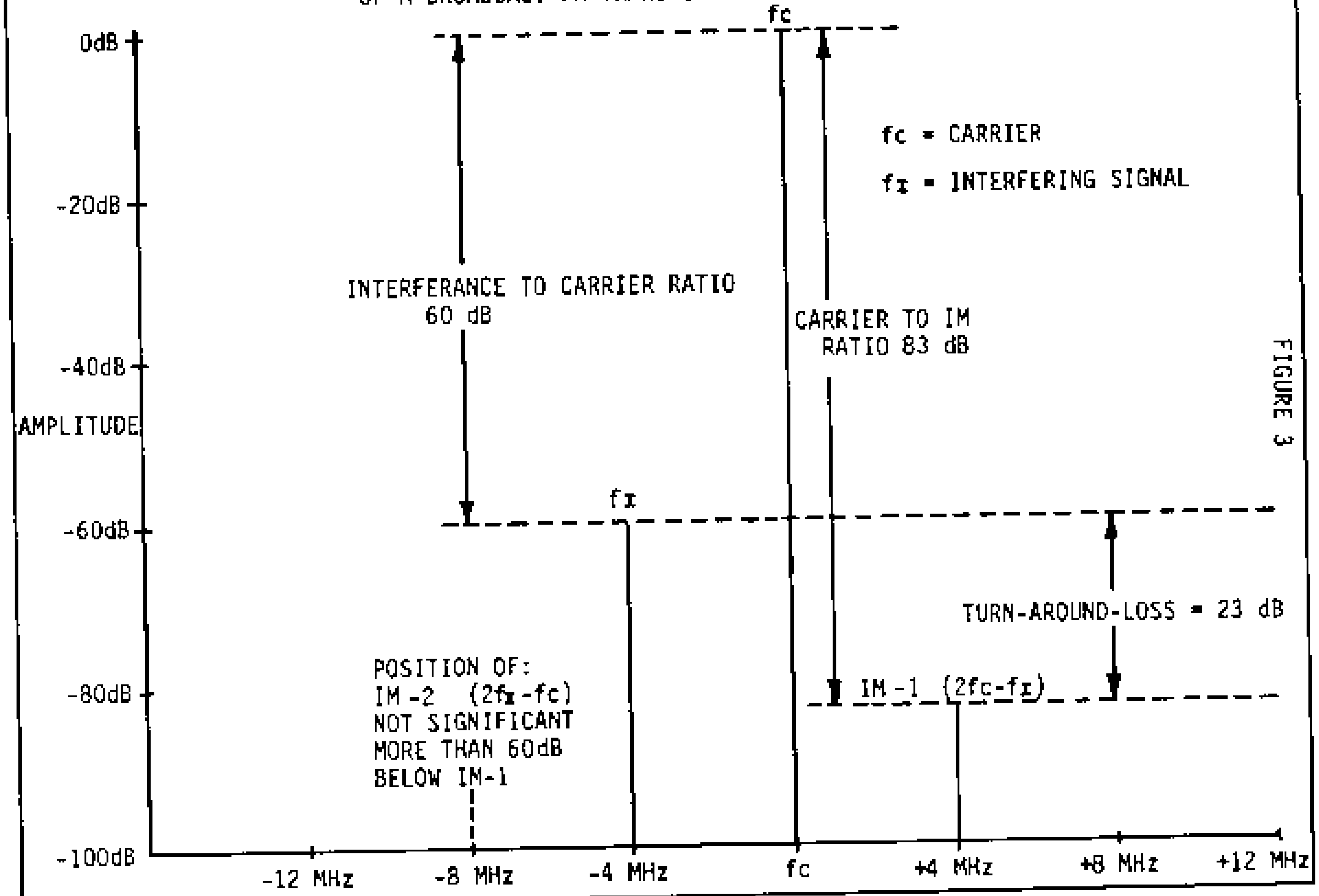


FIGURE 3

II. INTERMODULATION AS A FUNCTION OF "TURN-AROUND-LOSS".

"Turn-Around-Loss" or "Mixing Loss" describes the phenomenon whereby the interfering signal mixes with the fundamental and its harmonics within the non-linear output device. This mixing occurs with a net conversion loss, hence the term "Turn-Around-Loss" has become widely used to quantify the ratio of the interfering level to the resulting IM level. A "Turn-Around-Loss" of l0dB means that the IM product fed back to the antenna system will be l0dB below the interfering signal fed into the transmitter's output stage.

"Turn-Around-Loss" will increase if the interfering signal falls outside the passband of the transmitter's output circuit, varying with the frequency separation of the desired signal and the interfering signal. This is because the interfering signal is first attenuated by the selectivity going into the non-linear device and then the IM product is further attenuated as it comes back out through the frequency selective circuit.

"Turn-Around-Loss" can actually be broken down into the sum of three individual parts:

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

(2) The attenuation of the out-of-band interfering signal due to the selectivity of the output stage.

(3) The attenuation of the resulting out-of-band IM products due to the selectivity of the output stage.

Of course, as the "Turn-Around-Loss" increases, the level of undesirable intermodulation products is reduced and the amount of isolation required between transmitters is also reduced.

III. EQUIPMENT PARAMETERS THAT AFFECT INTERMODULATION LEVELS.

The interfering signal must be coupled into the transmitter's output stage before the IM products are produced and the output level of the intermodulation products will be related to the interfering signal level. The two parameters (outside of the filterplexing.equipment) that most affect the interfering signal level into the transmitter's output circuit are the output loading and the circuit's frequency selectivity (loaded "Q"). These two parameters are interrelated because the degree of output loading will change the loaded "Q" of the output circuit while also affecting the return loss of the interfering signal looking into the output circuit.

"Output Return Loss" is a measure of the amount.of interfering signal that is coupled into the output circuit versus the amount that is reflected back from the output circuit without interacting with the nonlinear device. To understand this concept more clearly, we must remember that although the output circuit of the transmitter is designed to work into a fifty ohm load, the output source impedance of the transmitter is not fifty ohms. If the source impedance were equal to the fifty ohm transmission line impedance, half of the transmitter's output power would be dissipated in its internal output source impedance. The transmitter's output source impedance must be low compared to the load impedance in order to achieve good efficiency. The transmitter therefore looks like a voltage source driving a fifty ohm resistive load. While the transmission line is correctly terminated looking toward the antenna (high return loss), the transmission line is greatly mismatched looking toward the output circuit of the transmitter (low return loss). This means that power coming out of the transmitter is completely absorbed by the load while interfering signals fed into the transmitter are almost completely reflected by the output circuit.

The small portion of the interfering signal that is not reflected is what causes intermodulation products to be generated. Obviously the lower the output source impedance, the more complete the reflection (lower return loss), with the result being less production of intermodulation products.

The transmitter output circuit loading control directly affects the source impedance and therefore affects the efficiency of coupling the interfering signal into the output circuit where it mixes with the other frequencies present to produce IM products. Generally, as the output circuit is more heavily loaded, the source impedance increases and the output return loss of the transmitter increases. This allows more interference to enter the output circuit causing more IM for a given level of interference. Another way of saying this is that heavy loading reduces "Turn-Around-Loss Light loading causes the source impedance to decrease thereby reducing the output return loss looking into the output circuit and preventing interference from entering the output circuit. The result is I that light loading increases "Turn-Around-Loss".

The basic in-band conversion loss is directly related to the "Output Return Loss" as a function of output loading control setting. In Addition, the output loading control setting will change the output circuit bandwidth (loaded "Q") and therefore also affect the amount of attenuation that out-of-band signals will encounter passing "into" and "out of" the output circuit.

Second harmonic traps or low pass filters in the transmission line of either transmitter have little effect on the generation of intermodulation products. This is because the harmonic content of the interfering signal entering the output circuit of the transmitter has much less effect on IM generation than the harmonic content within the non-linear device itself. The resulting IM products fall within the passband of the lowpass filters and outside the reject band of the second harmonic traps, so these devices offer no attenuation to IM products.

Figure 4 gives a summary of equipment parameters that affect intermodulation levels as a function of "Turn-Around-Loss".

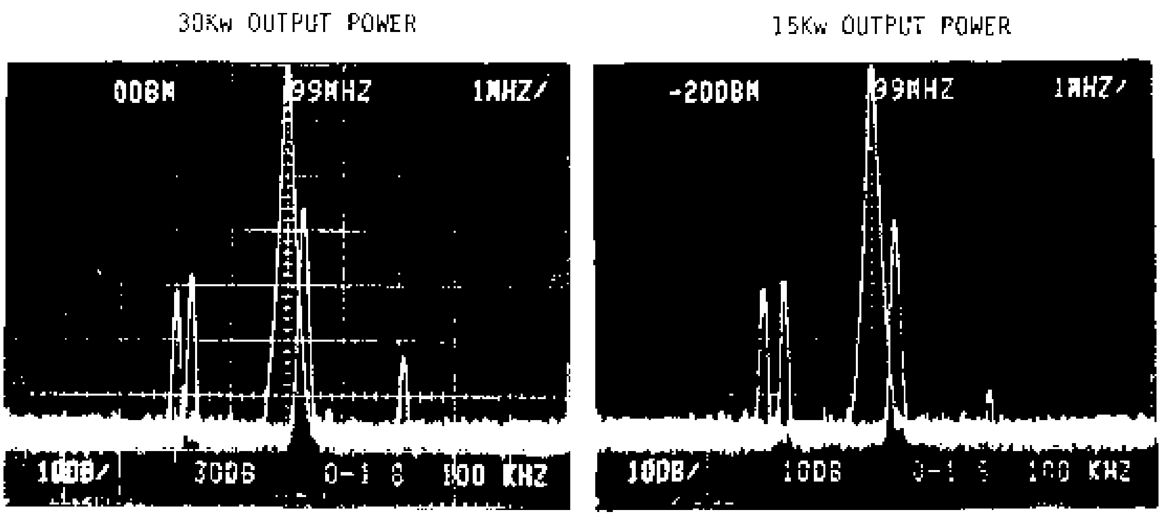
Figure 5 shows two spectrograms of the intermodulation product and its relationship to the carrier level, the interfering signal level (Turn -Around-Loss), and the "Output Return Loss".

FIGURE 4

EQUIPMENT PARAMETERS THAT AFFECT INTERMODULATION LEVELS

1. "OUTPUT RETURN LOSS" (REFLECTION OF INTERFERING SIGNAL DUE TO THE MISMATCH PRESENTED BY THE TRANSMITTER'S OUTPUT SOURCE IMPEDANCE)
2. SELECTIVITY OR LOADED "Q" OF THE TRANSMITTER'S OUTPUT CIRCUIT (ATTENUATES OUT-OF-BAND SIGNALS)
3. EFFECT OF LOW PASS FILTERS OR SECOND HARMONIC TRAPS (NO EFFECT)

FIGURE 5



INTERFERING SIGNAL IS 2.0 MHz BELOW THE CARRIER FREQUENCY AND 4OdB BELOW THE CARRIER LEVEL.

SPECTRAL COMPONENTS FROM LEFT TO RIGHT ON EACH SPECTROGRAM ARE AS FOLLOWS:

1. Level of the interfering signal reflected by the transmitter output stage.
2. Level of the interfering signal going into the transmitter output stage.
3. Level of the desired carrier.
4. Level of the desired carrier reduced by the directivity of the directional coupler.
5. Level of (2fc - fi) 3rd order intermodulation product.

SPECTRAL COMPONENTS #2 AND #4 WERE SHIFTED UP IN FREQUENCY BY 400 KHz ON THE DISPLAY TO MAKE THEM VISIBLE FOR COMPARISON. THE RATIO OF #1 TO #2 IS THE "OUTPUT RETURN LOSS". THE RATIO OF #2 TO #5 IS THE "TURN-AROUND-LOSS".

IV. TEST SETUP TO MEASURE THE "TURN-AROUND-LOSS" OF AN FM BROADCAST TRANSMITTER.

Figure 6 shows a block diagram of the test setup used to measure the "Turn-Around-Loss" and "Output Return Loss" of the Broadcast Electronics Model FM-30, 3OKw FM broadcast transmitter. This configuration uses non-directional capacitive coupling probes in each transmitter's transmission line to cross-couple energy between two transmitters. Coupling of the interfering signal at a level of as much as 4OdB below each carrier level was possible with this test setup. A directional coupler with 45dB coupling and 32dB directivity was used to feed samples to a Tektronix Model 492 spectrum analyzer. The sample from the directional coupler port labeled "forward" contains the desired carrier, the intermodulation products coming out of the transmitter, and the interfering signal level reflected back out of the transmitter. The sample from the directional coupler port labeled "reflected" contains the interfering signal level being fed into the transmitter as well as the other components reduced in level by the directivity of the directional coupler.

Figure 7 shows a similar setup except that the capacitive probes were replaced with directional couplers having a coupling factor of 3OdB and a directivity of 3OdB. This setup allows lower level measurements to be made with cross-coupling in the 6OdB to 7OdB range. The results using either type of coupling arrangement were nearly identical.

Figures 8 and 9 show views of the test set up used at Broadcast Electronics.

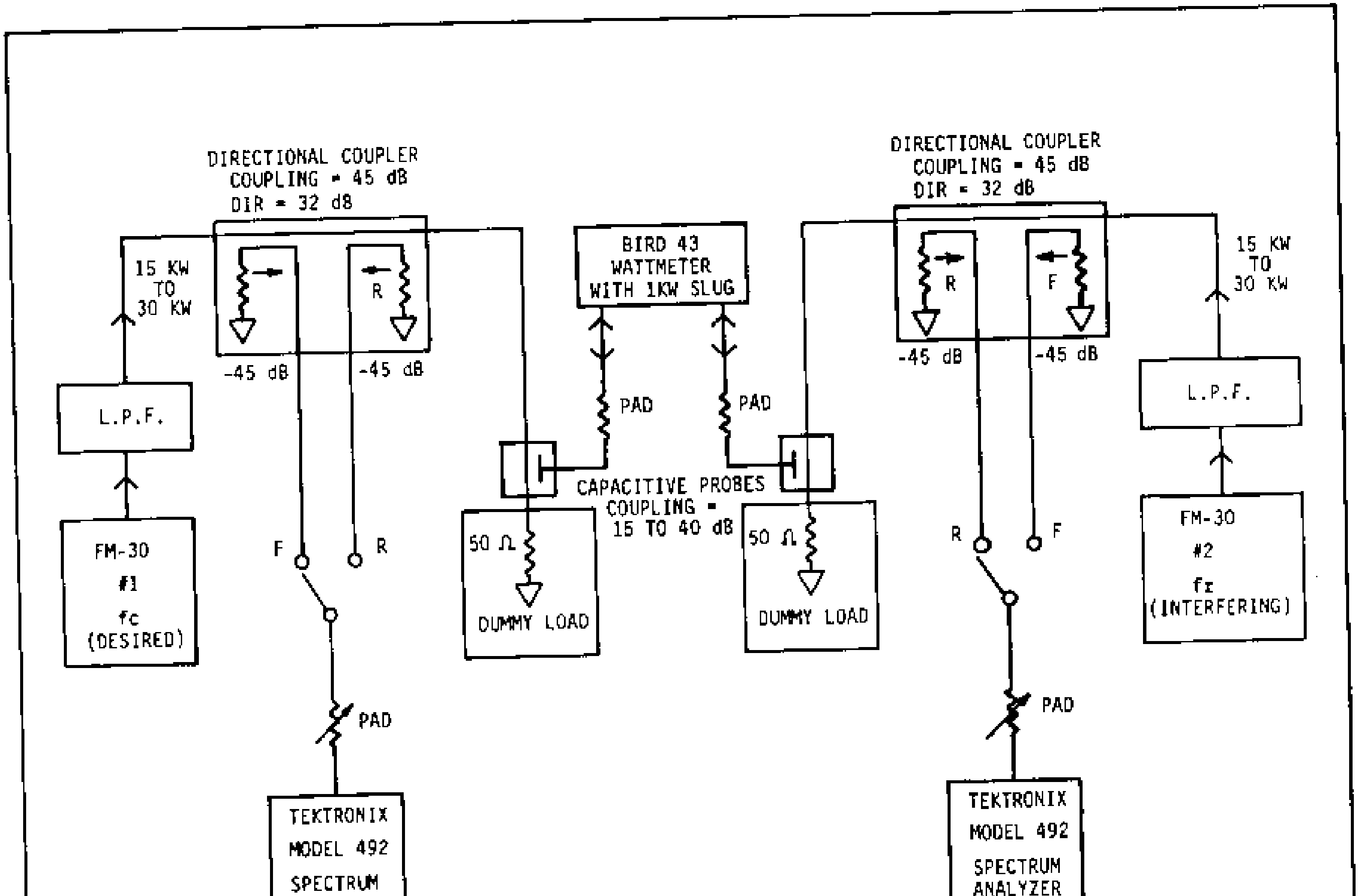


FIGURE 6
HIGH COUPLING TEST SET-UP

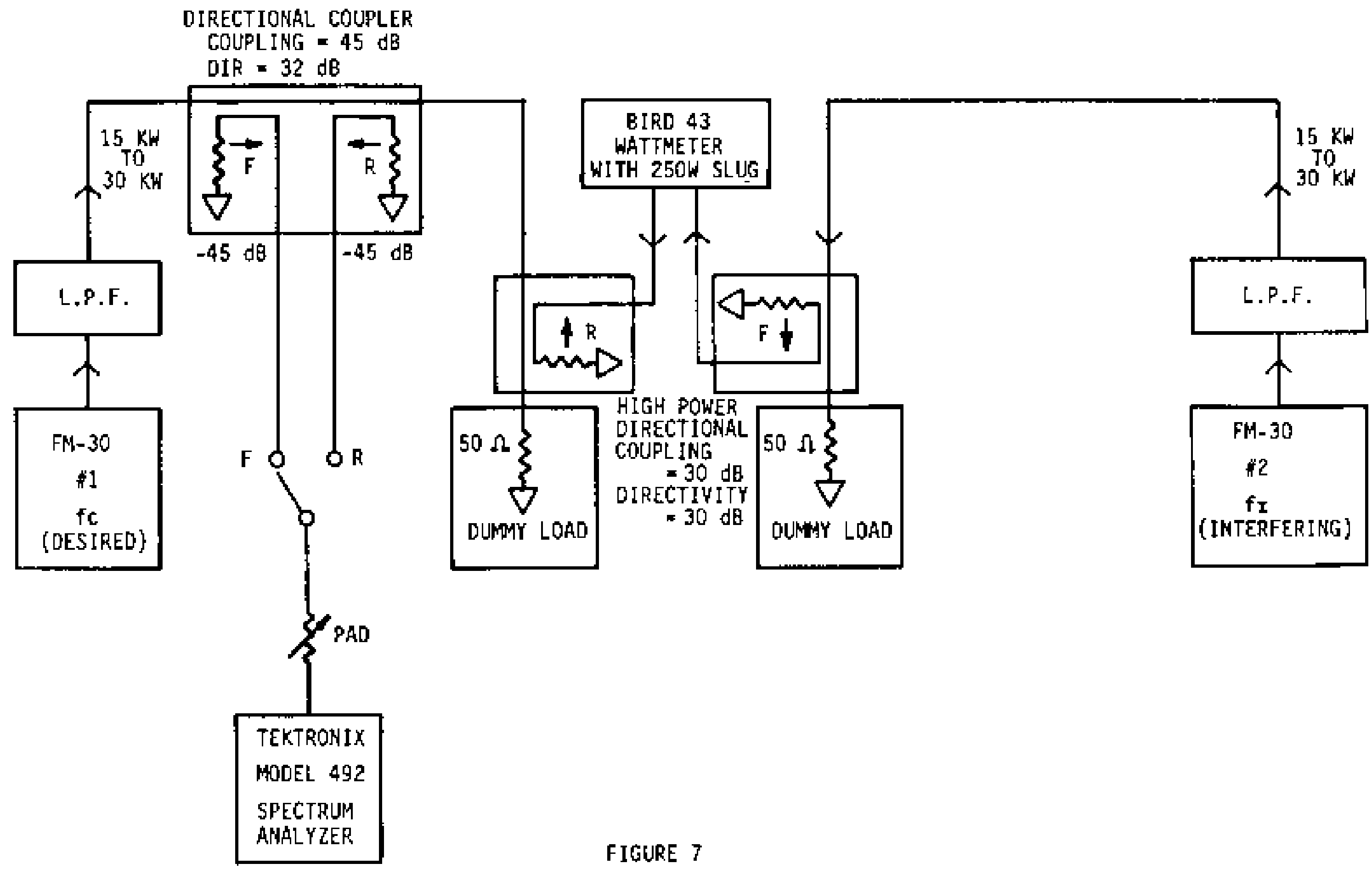


FIGURE 7
LOW COUPLING TEST SET-UP

FIGURE 8 - THE BROADCAST ELECTRONICS MODEL FM-30
TRANSMITTERS ON TEST WITH CROSS COUPLING EQUIPMENT

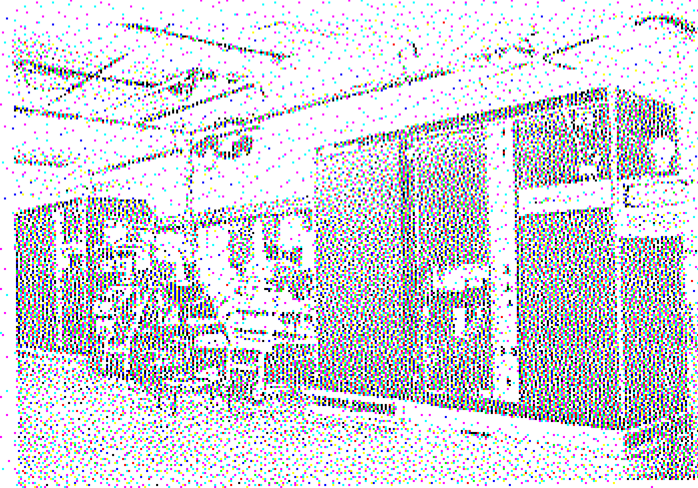
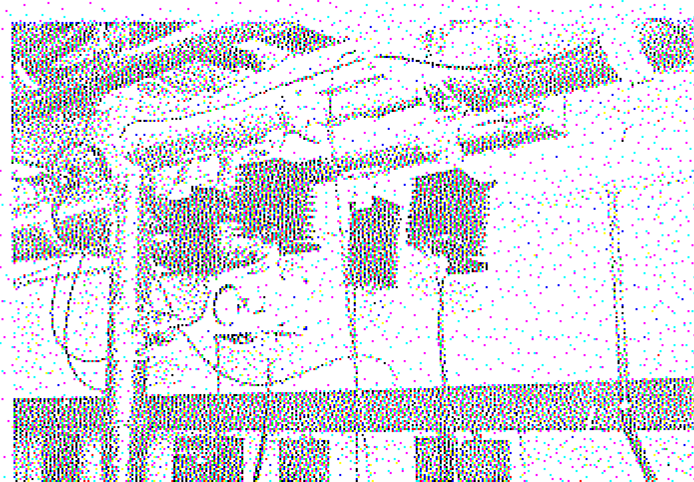


FIGURE 9 - CLOSE UP OF COUPLERS AND PADS



V. MEASURED DATA USING TWO BROADCAST ELECTRONICS MODEL FM-30 TRANSMITTERS

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TABLE I

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B.E.I. FM-30 @3OKw OUTPUT POWER FREQUENCY SEPARATION (fc TO fi) MHz

	0.8	2.0	4.0	6.0	8.0	10.0
INTERFERENCE LEVEL BELOW CARRIER---	40dB	40dB	40dB	40dB	40dB	40dB
TURN-AROUND-LOSS ----------------------	5dB	15dB	24dB	26dB	32dB	38 dB
INTERMODULATION LEVEL BELOW CARRIER	45dB	55dB	64dB	66dB	72de	78dB
OUTPUT RETURN LOSS TO INTERFERENCE	19dB	4.0dB	2.0dB	1.5dB	l.0dB	0.5dB

TABLE 2

B.E.I. FM-30 @15Kw OUTP POWER FREQUENCY SEPARATION (fc TO fi) MHz.

	0.8	2.0	4.0	6.0	8.0	10.0	
INTERFERENCE LEVEL BELOW CARRIER	40dB	40dB	40dB	40dB	40dB	40dB	
TURN-AROUND-LOSS ----------------------	20dB	20dB	34dB	42dB	44dB	49dB	
INTERMODULATION LEVEL BELOW CARRIER	60dB	60dB	74dB	82dB	84dB	89dB	
OUTPUT RETURN LOSS TO INTERFERENCE	1.5dB	1.5dB		l.0dB	l.0dB	0.5dB	0.0D

Figure 10 shows curves giving "Turn-Around-Loss" as a function of frequency separation, power output, and interference level for the Broadcast Electronics model FM-30 transmitter.

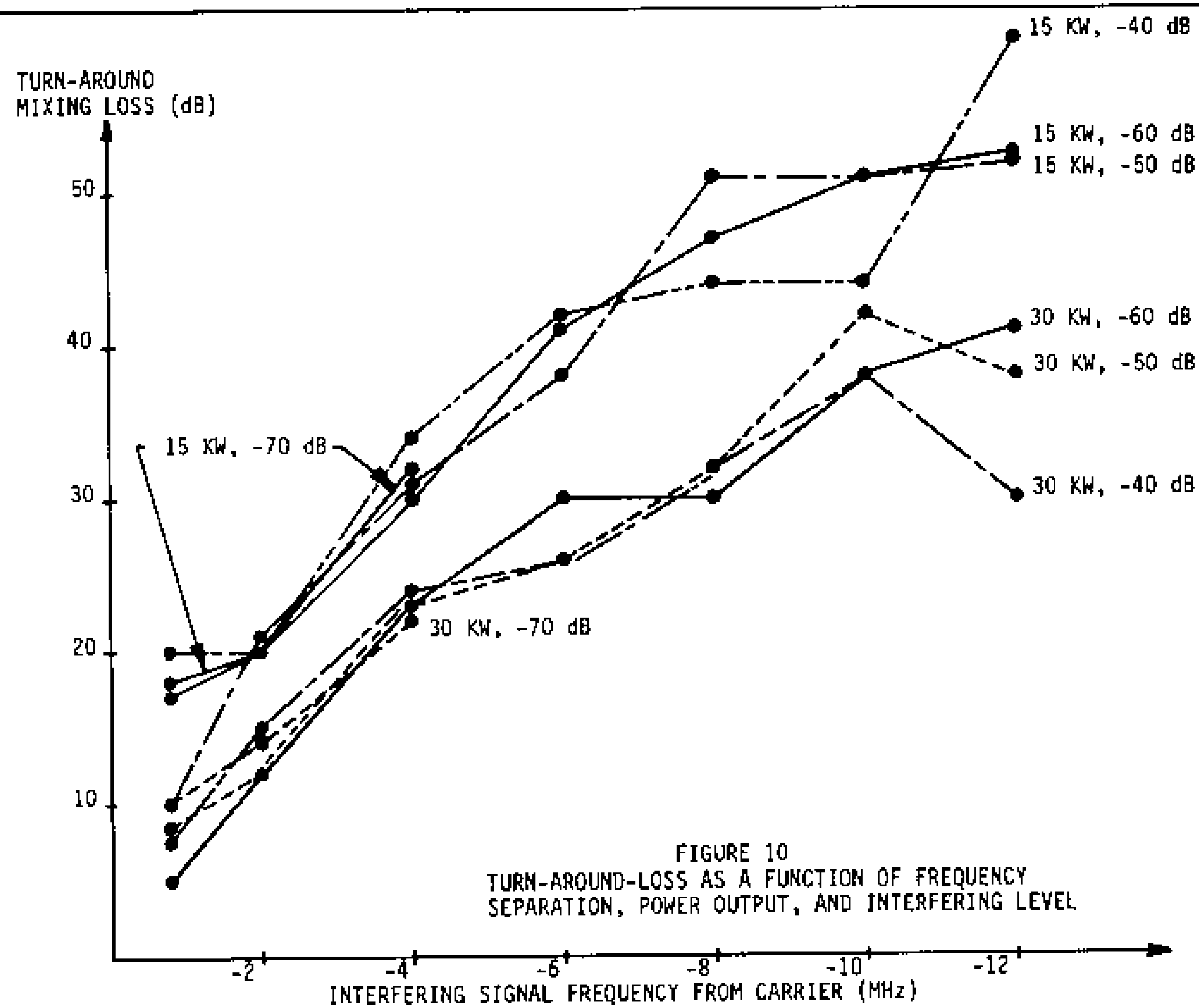

FIGURE 10
TURN-AROUND-LOSS AS A FUNCTION OF FREQUENCY SEPARATION, POWER OUTPUT, AND INTERFERING LEVEL

VI. CONCLUSIONS

1. "Turn-Around-Loss" is a function of the particular non-linear device and the amount of loading on its output circuit.

2. "Turn-Around-Loss" increases as the interfering signal and the resulting IM products are moved away from the carrier and out of the output circuit passband.

3. "Turn-Around-Loss" will be least when the interfering signal is within the transmitter's passband.

4. As the interfering level below carrier level is reduced below 4OdB, the "Turn-Around-Lossit stays fairly constant, making it independent of the actual interfering level. Therefore Tables 1 & 2 can@be used as a good approximation to the a . ctual "Turn-Around-Loss" for the Broadcast Electronics FM-30 at any interfering level of less than 4OdB.

5. The dominant intemodulation product generated at each transmitter is at twice that transmitter's frequency minus the interfering transmitter's frequency (2fc - fi).

6. It would be helpful to have measured data on specific types of transmitters giving "Turn-Around-Loss" as a function of both frequency separation and transmitter output power (varying amounts of output loading).

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THE AUTHOR

Geoffrey N. Mendenhall earned his BEE degree fr the Georgia Institute of Technology in Atlanta, Georgia.

Mr. Mendenhall has designed communications and telemetry equipment for E.F. Johnson and Harris Corporation. He led the design efforts for both the Harris MS-15 product line and the Broadcast Electronics FX-30 FM exciter.

His practical field experience has involved engineering and operations work for several radio and television stations.

Mr. Mendenhall is presently serving as Vice President of Engineering for Broadcast Electronics Inc. in Quincy, Illinois. He is an active amateur radio operator and is experimenting with home satellite reception.

The author holds two U.S. Patents for electronic designs and is a registered professional engineer in the State of Illinois. He has authored numerous technical papers and is a member of the Institute of Electrical and Electronics Engineers.