AN EXPERIMENTAL STUDY OF IMAGE TERMINATION METHODS FOR LOW NOISE MIXERS

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ABSTRACT

Relations are given to determine image response rejection and the relative phase changes of major mixer frequency products. Image recovery mixer tests will be described which led to the conclusion that it does not have a reactively terminated image response.

Single Sideband Mixer Phase and Amplitude Unbalance

The effects of either amplitude or phase unbalance in a 90° IF hybrid for image response removal from the desired sideband has been treated recently by Gorwara.[1] Curves in Figure 1 show theoretical data for both amplitude and phase unbalance of IF signals versus image suppression. This data has been verified by measurements. Equations for obtaining the curves are given in the Figure.

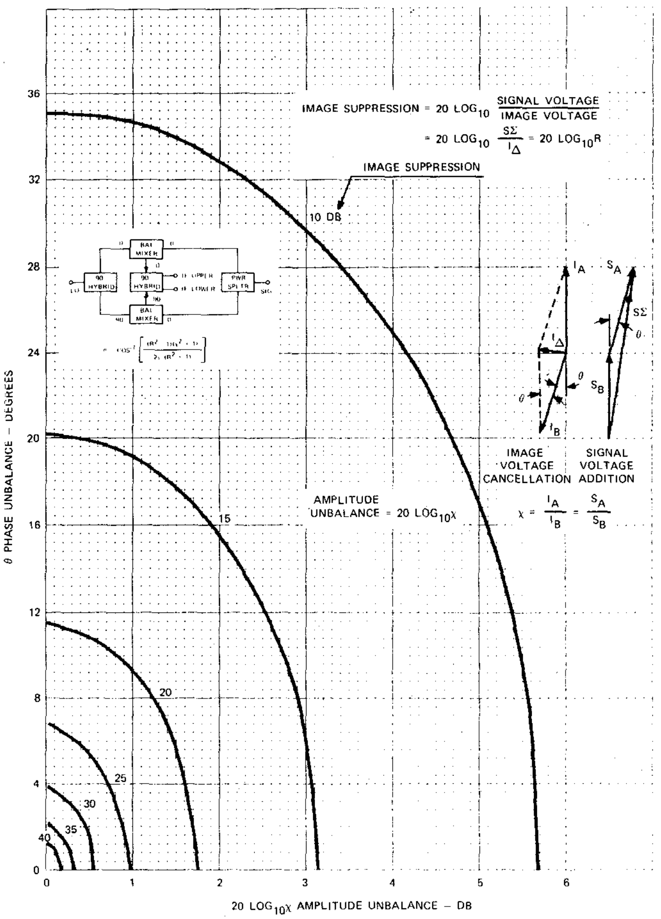

FIGURE 1. EFFECTS OF PHASE AND AMPLITUDE UNBALANCE ON IMAGE SUPPRESSION

Phase of Mixer Frequency Products

The phase of the principal frequencies in a mixer may be described by equations that allow complex circuits to be analyzed mathematically or vectorially. Both techniques will be used in later discussions. Equations for relative phases that were obtained from measurements are as follows:

Equation	Condition
$\Theta_I = \Theta_S - 2\Theta_C$	$f_s >$ or $< f_c$
$\Theta_{IFS} = \Theta_S - \Theta_C$	$f_s > f_c$
$\Theta_{IFS} = \Theta_C - \Theta_S$	$f_c > f_s$
$\Theta_{IFI} = \Theta_I + \Theta_C$	$f_s > f_c$
$\Theta_{IFI} = -(\Theta_I + \Theta_C)$	$f_c > f_s$

Where
Θ_S = Phase of signal f_s
Θ_C = Phase of local oscillator f_c
Θ_I = Phase of image f_I
Θ_{IFS} = Phase of signal IF
Θ_{IFI} = Phase of image IF

Positive rotation is assumed to be counterclockwise (CCW). The image frequency is the only component rotating in the negative or clockwise (CW) direction. All IF signals rotate CCW whether they be caused by a CCW or CW rotating signal above or below the local oscillator (LO) frequency.

A phase delay is entered in the equations as a negative number for CCW rotating signals and as a positive number for CW rotating signals so that a net positive angle calculation shows CCW rotation and vice versa. A phase delay for a vector will cause rotation opposite to its normal rotation.

1 dB Conversion Loss Measurements

Figure 2(a) shows the test circuit used to obtain a 1 dB conversion loss at 6.5 GHz. The input signal f_s was 70 MHz above f_c. The filter was tuned to f_s so that the reflected received signal could be either terminated or reflected back to the mixer with variable phase.

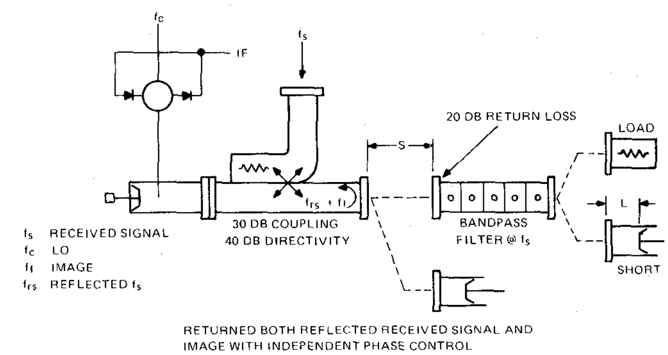

FIGURE 2a. 1 DB CONVERSION LOSS SET-UP AT 6 GHz

The results of Fekete[2] which showed the image IF added to the signal IF on a voltage or 20 log basis was verified. We also found that the reflected received signal was just as important as the image when it was returned to the mixer since its IF also added to the desired IF on a voltage basis.

Adjustment of the spacer length S and plunger position L resulted in a 1 dB conversion loss. Noting the plunger and spacer travel and the resultant IF output, it was possible to calculate the vector addition of the reflected received signal and the image as their phase changed. These calculations agreed with the measured data.

A set up given in Figure 2(b) was used to measure noise figure when both the image and received signal were returned to the mixer. This test was later noticed to be similar to the one reported by Anand[3]. A 3.8 dB NF was obtained without resorting to matching between mixer and IF amplifier. The plunger was set for minimum conversion loss to measure noise figure.

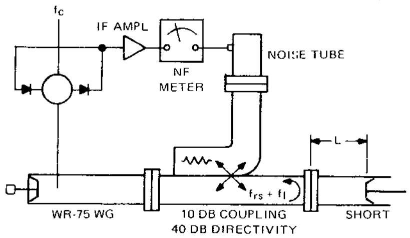

FIGURE 2b. 3.8 DB NF AT 11 GHz BY RETURNING REFLECTED RECEIVED SIGNAL AND IMAGE (NF IS SSB)

Image Recovery Mixer Tests

After unsuccessful attempts to obtain better than 5 dB NF on an 11 GHz image recovery mixer (IRM), tests were begun to understand this circuit. The significant tests only are given and not necessarily in time sequence.

Test 1

Suspecting that the noise from each balanced mixer was not acting as a coherent signal in the IF hybrid, a bandpass filter was put in the f_s line next to the noise figure tube so that 10 dB attenuation (using noise diode scale on meter) remained between the mixer and the filter to obtain isolation. Good noise figure could be measured out of one hybrid port; the NF was ∞ at the other IF hybrid output port. This showed that noise from a single source could be added and cancelled as a coherent signal through the IF 90° hybrid; therefore, the IRM contained more than one noise source at the image response.

Test 2

The return loss was measured at the image frequency and at the signal frequency looking into the mixer signal input. The values were approximately the same indicating no reactive termination at the image frequency that was visible from the mixer input.

Test 3

Figure 3 was drawn to show the image frequency phase along two paths between the two mixers. The image IF phase would be the same if the image frequency went from one mixer to the other, or if reflection of each mixer image occurred at the f_s junction to cause each mixer image to be returned to the same mixer.

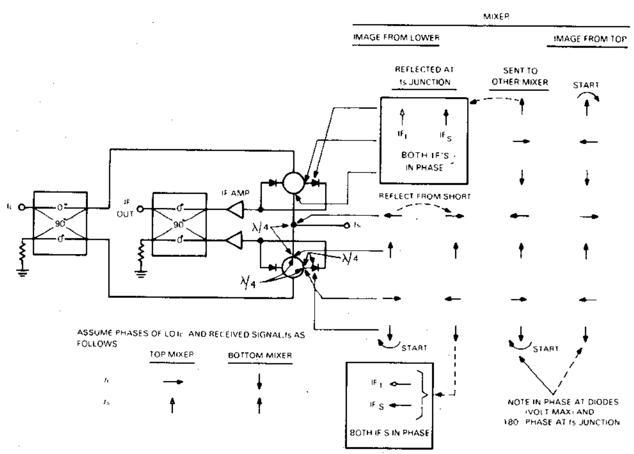

FIGURE 3. POSSIBLE PATHS OF IMAGE FREQUENCY IN IRM

Test 4

An RF probe was connected to a spectrum analyzer and was moved across the microstrip lines between the two mixers. A deep null of the image frequency was obtained at the junction of the f_s line to the mixer as expected. Following the circuit in Figure 3, a maximum was obtained $\lambda/4$ further at the hybrid ring on the signal side, a minimum (but not a null) on the hybrid ring port connected to the mixer diode, and a voltage maximum at the mixer diode. This would indicate an open circuit at the image frequency if indeed the image response was reactively terminated. Note that either path of the image frequency in Figure 3 could cause these standing wave patterns.

Test 5

RF signals were separately applied above and below f_c and measurements taken on the phase and amplitude of the IF voltages at the 90° IF hybrid. Table I shows the results. Both RF signals were then applied but frequency offset to be able to identify the IF voltages of each on a spectrum analyzer. With both signals applied, the IF outputs were the same as when either RF signals was applied. When the IF frequencies were brought together by shifting the RF frequencies, the combined outputs were observed to increase above the individual levels. This appeared strange since port 2 of the hybrid had two signals 180° out of phase and equal in amplitude. By careful tuning, a partial cancellation of the IF signals at port 2 could be observed on a sampling oscilloscope, but even though the RF carriers were stabilized, they were too jittery to cause a complete cancellation. Note proof of IF rotation being CCW from the tests in Table I.

f_L (−70, IMAGE FREQ) — f_c (0, LO) — f_u (+70, SIGNAL FREQ)

MEAS BY	INPUT		IF HYBRID TERMINALS OUT, DBM 1	2	3	4
VECTOR VM	f_u		0 ∠0°	0 ∠+90°	+3	-22
VECTOR VM	f_L		0 ∠0°	0 ∠-90°	-22	+3
SPEC. ANAL.	f_u & f_L OFFSET	f_u:	0	0	+3	-22
		f_L:	0	0	-22	+3

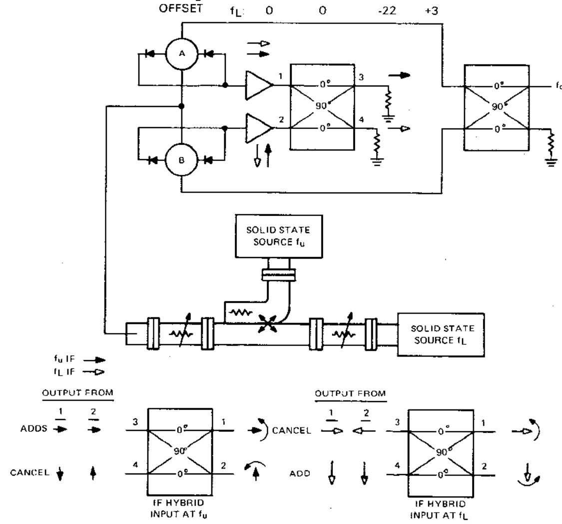

TABLE 1. SIGNALS FED TO BOTH SIDEBANDS OF IMAGE RECOVERY MIXER

Test 6

Noise figure was measured at the output of each mixer (before IF hybrid) to learn effects of image noise separation in the IF hybrid. The RF circuits were not disturbed so that the image return paths were unchanged. The noise figure was the same for the individual mixers as for the combined outputs; therefore, the hybrid did not reduce the noise.

Test 7

Conversion loss tests were made to see if the problem was in signal level or noise. The conversion loss of the individual mixers or for the combined outputs were all 3.5 dB. The noise figure measured 5.5 dB. The problem then appeared to be noise. Following the works of Mumford[4] and Neuff[5], noise figure curves were made for double and single response mixers. Figure 4 shows the results. Since matching had been unsuccessfully attempted between mixer and preamp to lower NF, it was believed that the noise level could not be lowered any further. Inspection of the curves shows that a 3.5 dB conversion loss will give the 5.5 dB NF that was measured if the IRM was broadband. NF of IF was 1.5 dB.

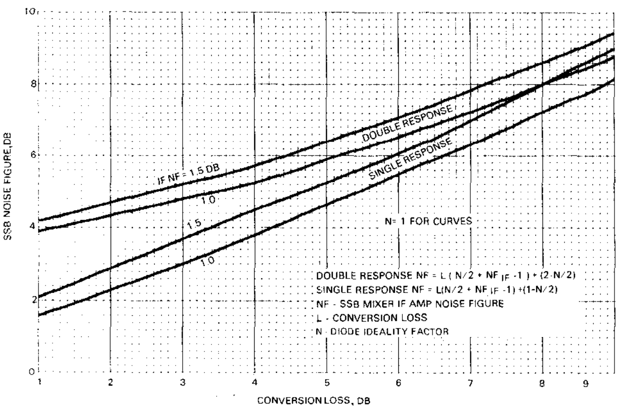

FIGURE 4. NOISE FIGURE OF SINGLE AND DOUBLE RESPONSIVE MIXERS

Test 8

Realizing that the IF impedance of the IRM output may provide a clue to the image response termination (response is used here to define the undesired mixer response at the image frequency and is not to be confused with the image frequency), tests were made on a single balanced mixer when its spacing to a bandpass filter was varied and also tests were made on two of these balanced mixers when connected as an IRM and the spacing of the two balanced mixers was varied. See Figures 5, 6, and 7.

While much information is contained in these curves, the most significant is the period of the IF impedance cycle. A variable positioned filter next to a balanced mixer will cause the IF impedance to repeat each half wavelength. If the IRM caused the image frequency to see a short at the signal input junction, the IF impedance should repeat every half-wavelength between each mixer and the junction, or each full wavelength in distance between the two balanced mixers. If the image frequency merely went to the other mixer, the IF impedance values would repeat each half wavelength between the two balanced mixers. This one test is the only positive way that was revealed to determine the image frequency path without disturbing the circuit.

Inspection of Figures 6 and 7 show the IF impedance repeated in a half wavelength, which is positive proof that the image of one mixer is returned to the other mixer and not to itself.

The strange behavior in the second half cycle is not understood, but inspection of Figure 7 shows that a region was reached that required a high LO power to reduce conversion loss. The single sideband nature of the IRM was not destroyed in this strange region. The gap in the data resulted from the shift to lines that had double bends on each side.

Conclusions from IRM Measurements

Considering all these facts, we have concluded that the IRM, whether using single or double balanced mixers, does not reactively terminate the image frequency response and lower the image noise contribution as has been predicted.[6,7,8,12] This circuit is a clever way to return the image of one mixer to another identical mixer with good isolation of the image frequency in the input signal line. The 90° hybrid also serves only as a combiner to recover the desired outputs of the two mixers and does not remove the image response noise, even though it does remove the image signals from the desired response. This conclusion says that the IRM is not equivalent to the same circuit configuration using band pass filters as shown in Figure 8.

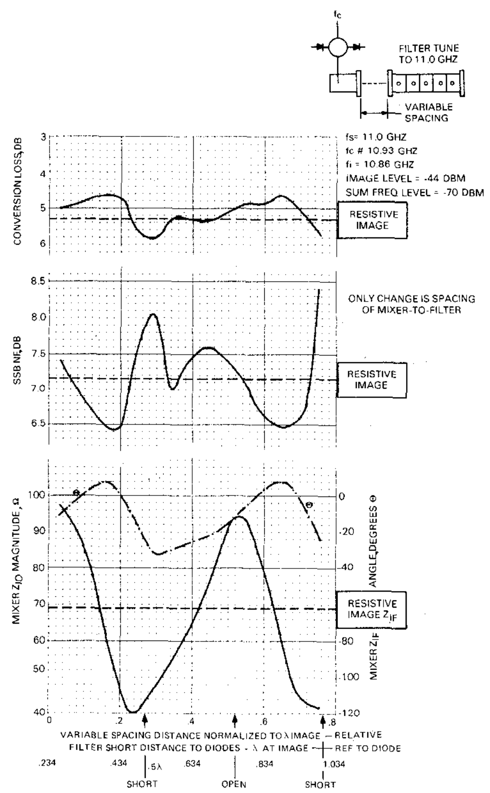

FIGURE 5. EFFECTS OF MIXER-TO-FILTER SEPARATION CHANGES

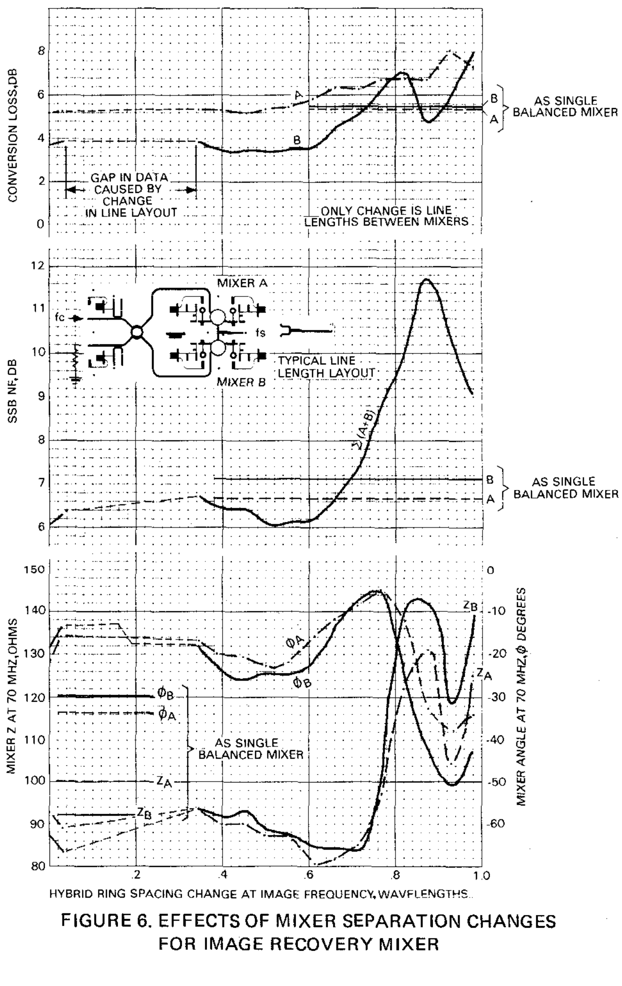

FIGURE 6. EFFECTS OF MIXER SEPARATION CHANGES FOR IMAGE RECOVERY MIXER

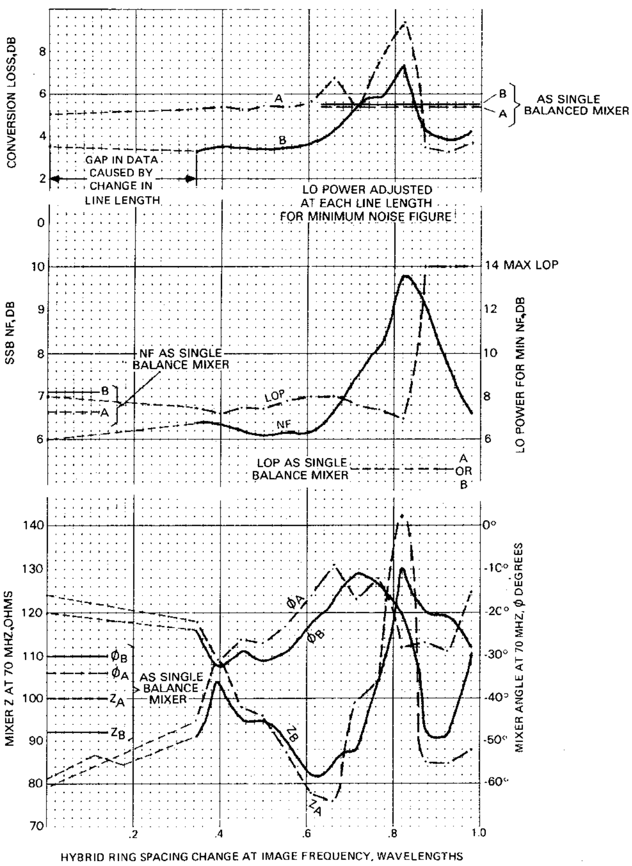

FIGURE 7. EFFECTS OF MIXER SEPARATION CHANGES FOR IMAGE RECOVERY MIXER

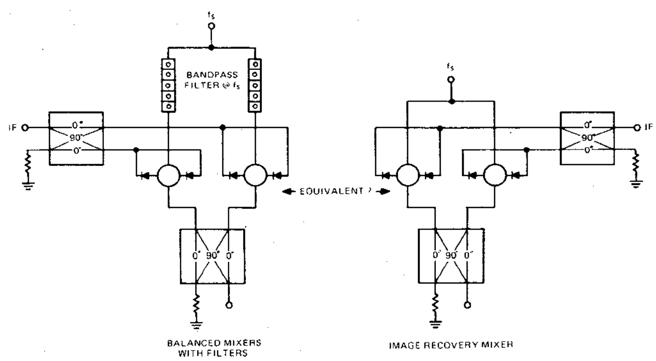

FIGURE 8. EQUIVALENT CIRCUIT FOR IRM

Conclusions

These observations have suggested many other conclusions.

1. Many authors have reported best noise figure at an image open[9], image short[10], and even in between[11]. Since minimum conversion loss usually coincides with minimum noise figure, could this difference be explained by the change in the generated image phase which would require different return path line lengths to cause the image intermediate frequency (IF) to be in phase with the desired IF signal?

2. The phase of the generated image depends on the diode and perhaps on the impedance seen by the diode. We have seen a phase offset of the image compared to the received signal when the reflected received signal and image frequency are sent to a second mixer through a circulator in the signal input line and phased to cause their IF outputs to add. This phase offset between f_s and F_I was eliminated when the image and reflected received signal were sent back to the same mixer, suggesting a synchronizing effect in the mixer diode which generated the image. See Figure 9.

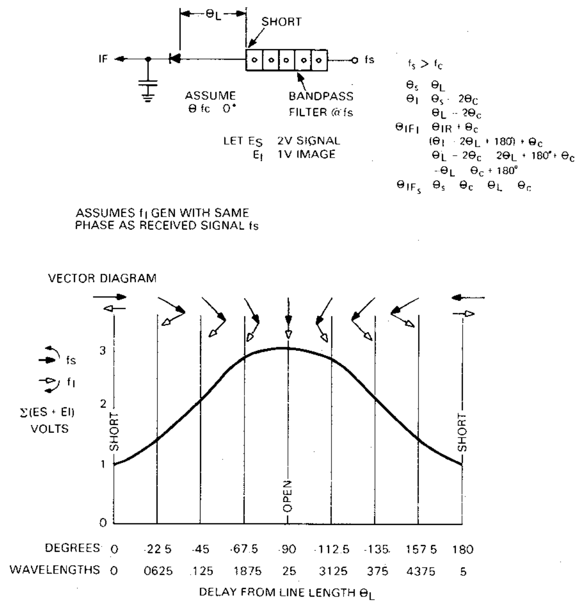

FIGURE 9. CALCULATED PHASE OF REFLECTED IMAGE FREQUENCY

3. It is difficult to phase the image frequencies in an IRM for minimum conversion loss over a broad band because the image frequency from one balanced mixer is the result of two images being combined (from two diodes) and then sent to a second mixer which splits this image between two diodes. The image phase is dependent on the L.O. drive level and for the IRM the L.O. must be split twice, requiring close control of the L.O. power dividers and the diodes themselves.

4. A single balanced mixer that does not change NF over a 4 dB range of L.O. power will hold NF over only a 2 dB range in an IRM circuit.

5. Each diode in a mixer functions as an independent noise generator so that noise in the image response cannot be separated by a 90° IF hybrid that is fed by more than one mixer diode; that is, the image noise cannot be cancelled out. This says that the only way to suppress the image noise is to place a reactive termination at the image terminals that suppresses the noise power in this bandwidth.

6. The best noise figure will be obtained by a single diode that has both the reflected received signal and image returned to the same diode by a reactive load to cause all IF signals to be in phase.

7. When the reflected received signal was returned with the image, during the tests using Figure 2(a), the L.O. power dropped from about +18 dBm to about 0 dBm when minimum conversion loss was reached.

8. The equivalent of a series resonant circuit tuned to the image frequency that is connected from the f_s line "T" junction to ground should give noise improvement in the IRM.

9. The IRM should give minimum conversion loss each quarter wavelength from the f_s "T" junction to the mixer diodes.

Acknowledgements

This effort was made possible by the contributions of many sources. The continued discussions, leadership, and suggestions of Dr. Hal Sobol and Mr. Robert Hicks have been invaluable. I am thankful to many other people at Collins Radio for discussions on these findings, in particular to W.J. Thompson, F.E. Reisch, and C. Sirles. E Saenz designed the IF amplifiers used for most of the tests.

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