Investigation of a Single-Sideband Mixer Anomaly

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Abstract —**Measurements on a 6-GHz single-sideband (SSB) balun-coupled mixer revealed a feedthrough of RF signals between the two mixer sections that caused the IF outputs to be unbalanced at the ±90° local oscillator (LO) phase differences when using a ring diode quad. Using a bridge diode quad in this same mixer eliminated this IF output unbalance. These measurements also give conclusive evidence that the balun-coupled mixer has a short-circuited image frequency voltage with the ring diode quad and an open-circuited image frequency voltage with the bridge diode quad. These two image frequency impedance conditions are independent of circuit terminating impedances and solely depend on the image frequency current path being completed or interrupted by the ring or bridge diode quads, respectively.**

I. Introduction

The BALUN-COUPLED SSB mixer designed at 6 GHz with a ring diode quad was observed to be theoretically ideal in its layout, so it offered much promise in achieving a record low conversion loss. For a ±90° LO phase difference, the image frequency voltages should be 180° out of phase from the two mixer sections in the diode quad only, which should result in a very short image frequency current path around a monolithic ring diode quad structure. Theoretically perfect isolation existed to the image frequency voltage which should avoid any coupling loss. Essentially zero length existed between the RF signal and LO terminals at the diode package, which should maintain good image frequency phase and amplitude balance in the two mixer sections. The image frequency was so well balanced that it could rarely be seen in the signal input line. Measurements were then begun when the conversion loss could not be lowered below 5 dB.

A conversion loss of 2 dB was believed to be reasonable at 6 GHz for the SSB balun-coupled mixer. At *S*- through *Ku*-bands, Oxley achieved a 3-dB conversion loss in a similar phasing-type image recovery balun-coupled mixer that used two diode quads [1]. At 12 GHz, Dickens and Maki measured a 2-dB conversion loss on a comparable phasing-type mixer that used slot and coplanar transmission lines [2]. We had previously seen a 2-dB conversion loss at 11 GHz using a hybrid-coupled phasing-type mixer [3]. We were thus encouraged to pursue a detailed measurement program which will be described in this paper.

The theory of operation for this SSB balun-coupled mixer has been described in the literature [4]. The particular type of balun transmission lines used in this mixer have also been defined elsewhere [5].

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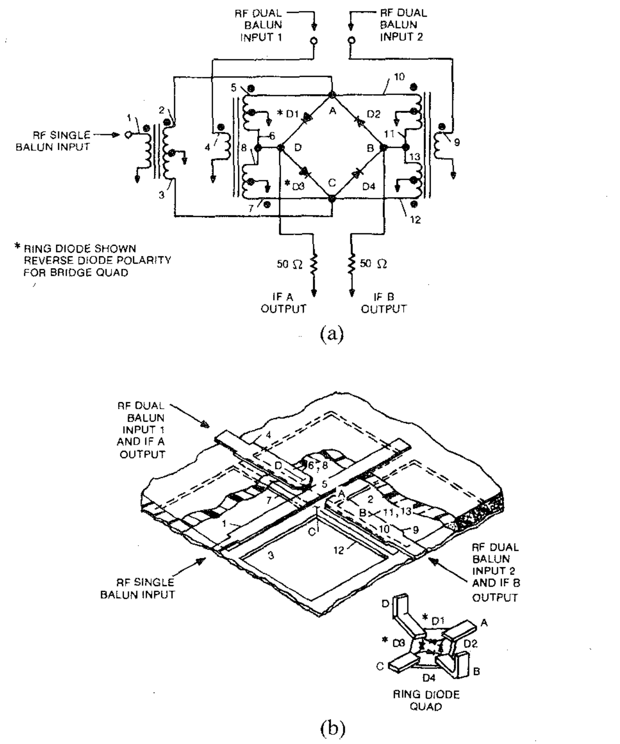
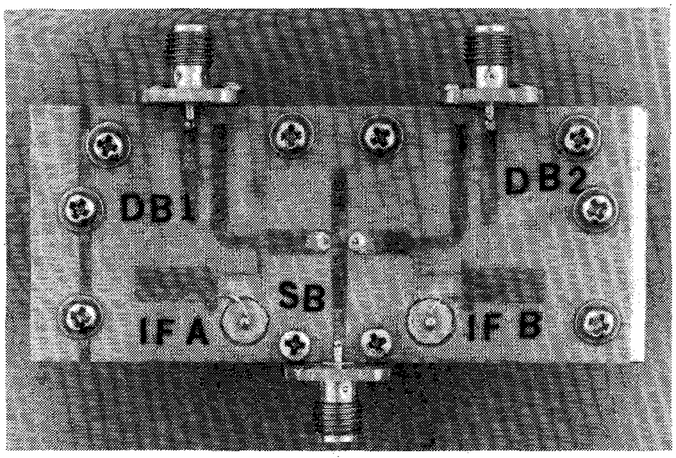


Fig. 1. SSB mixer circuit description used for testing. (a) Low-frequency equivalent circuit. (b) RF planar conductor layout.

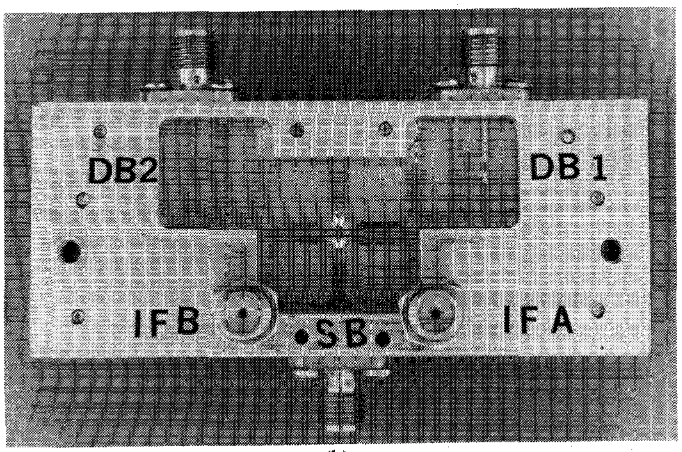
II. Description of Test Mixer and Test Conditions

The low-frequency equivalent circuit and planar layout drawing of the SSB mixer that was tested are shown in Fig. 1. The two drawings are directly related by the circuit function numbers that are equivalent in both drawings. The relative phase reference nodes *A*, *B*, *C*, and *D* at the diode package terminals are used later for deriving phase equations. The monolithic ring and bridge diodes were manufactured by Alpha Industries (DMF 4745 for the ring quad and DMF 6558 for the bridge quad). They were mounted on an Alpha 295-004 flat leaded package. Diodes *D*1 and *D*3 may be reversed on the drawings to change a ring to a bridge quad.

A photograph of the test mixer is shown in Fig. 2. Both types of diode quads were mounted in this same mixer. The balun intermediate frequency (IF) rejection filters that are connected to each dual balun input provides 50 dB of isolation to the 70-MHz IF present on the RF lines. Insertion loss of the filter to the 6-GHz RF is 0.3 dB. This filter is described in [5].



(a)



(b)

Fig. 2. SSB balun-coupled mixer used for testing. (a) Top view. (b) Bottom view.

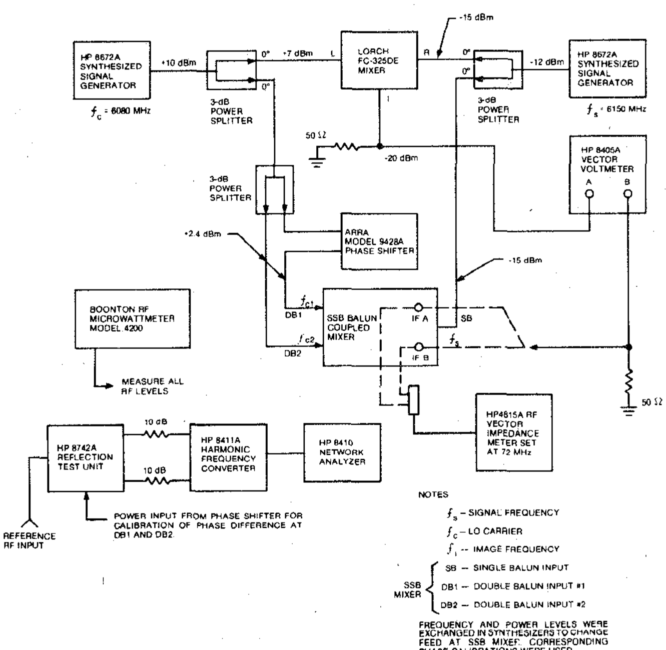


Fig. 3. Test equipment diagram.

The test equipment diagram in Fig. 3 defines all conditions for the stable control of frequencies, levels, and phases that are so necessary for this type of test. The RF phase shifter was calibrated at the LO frequency of 6080 MHz. The same micrometer readings were used at the signal frequency of 6150 MHz so the phase calibrations at the signal frequency do not occur at even 10° increments. The IF impedances were measured at 72 MHz to avoid interaction with the 70-MHz IF signals.

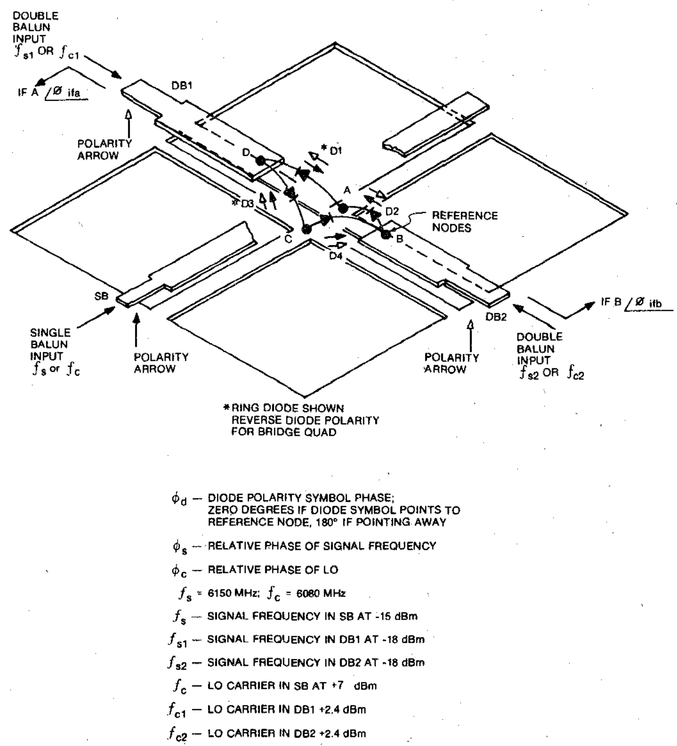


Fig. 4. SSB balun-coupled mixer test conditions, layout diagram.

The additional mixer was necessary for a reference to each IF phase reading so that each could be independently observed. This proved very useful in noting the dependence of one mixer section on the other when the phase of only one mixer section was changed.

The mixer layout diagram shown in Fig. 4 defines the conditions for all tests and includes the diode connection arrangements, balun identification, IF signal locations, and the RF signal and LO levels and frequencies when connected to different balun inputs. The relative phase polarity arrows are used in later discussions. The convention followed for all relative phase equations and calculations are defined elsewhere [6].

III. Ring Diode Quad Measurements

A. Signal in Single Balun, LO in Dual Balun

1) LO in Each Dual Balun

Connecting the signal frequency to the single balun should give the least conversion loss because of the presence of image frequency power recovery and elimination of the 0.3-dB RF loss in the IF rejection filters in the dual balun lines. This is also the preferred connection because the image frequency is isolated from all RF lines when the LO phase difference to the two mixer sections is ±90°.

The phase of the LO in DB1 was incremented in 10° steps over a 360° range to study the IF level and phase behavior because of the higher than expected IF losses and

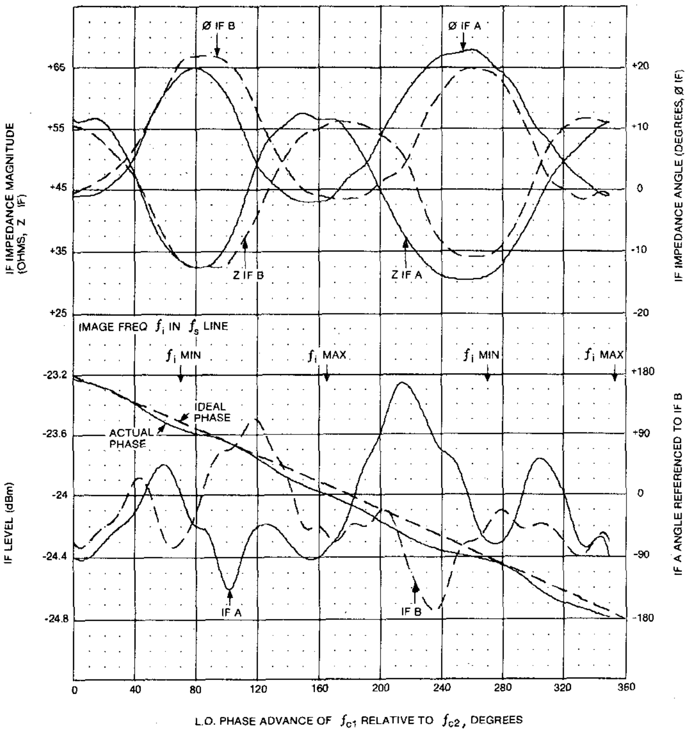


Fig. 5. Signal in single balun, local oscillator in each dual balun, ring quad.

TABLE I
SIGNAL IN SINGLE BALUN, LOCAL OSCILLATOR IN EACH DUAL BALUN, RING QUAD, PHANTOM VECTOR CALCULATED

SIGNAL FREQUENCY f_S = 6150 MHz; LO CARRIER FREQUENCY f_C = 6080 MHz
SINGLE BALUN SB INPUT: f_S AT -15 dBm
DUAL BALUN DB1 INPUT: f_{c1} AT +2.4 dBm
DUAL BALUN DB2 INPUT: f_{c2} AT +2.4 dBm
UNDISTURBED IF B MAGNITUDE AND PHASE: -22.2 dBm at 318°

PHASE f_{c1} REF f_{c2} DEGREES	IF A	IF B	72-MHz IMPEDANCE OHMS/DEGREES		PHANTOM VECTOR TO CHANGE IF B dBm/DEGREES	IF B PHASE REF TO PHANTOM PHASE-DEGREES
	dBm/DEGREES	dBm/DEGREES	IF A	IF B		
0	-24.4/142.4	-24.3/-33.5	56.5/-1	55.5/-0.5	-26.1/124.8	201.7
10	-24.4/133	-24.3/-35.5	56.5/-1	54.5/+0.5	-26.2/127.7	196.8
20	-24.3/123.4	-24.2/-37.4	56.0/0	52.5/+2	-26.4/130.2	192.4
30	-24.2/112.5	-24.1/-38.7	52.5/+2	50/+4	-26.6/132.0	189.3
40	-24.1/97	-23.9/-40.9	47.5/+5.5	47/+7	-27.0/135.7	183.4
50	-23.9/78.3	-24.0/-43.7	40.5/+11.5	42/+11.5	-26.8/141.3	175.0
60	-23.8/61.4	-24.3/-47.5	36.0/+16	37/+16.5	-26.2/146.6	165.9
70	-24.0/48.9	-24.3/-50.3	33.5/+19	33.5/+21	-26.1/150.8	158.9
80	-24.2/39.7	-24.1/-52.6	32.5/+20	32.5/+22	-26.3/156.0	151.4
90	-24.3/31.3	-23.8/-56	33/+18.5	32.5/+22	-26.5/164.9	139.1
100	-24.6/21.8	-23.7/-58.5	36/+15.5	33/+21	-26.4/170.0	131.5
110	-24.4/11.8	-23.6/-57	42/+10	36.5/+18	-26.7/169.9	133.1
120	-24.2/3	-23.5/-51.8	49.5/+4	41/+12.5	-27.4/163.0	145.2
130	-24.2/-5.4	-23.7/-44.5	54/+1	46.5/+7	-27.5/144.0	171.5
140	-24.3/-15.2	-23.9/-40.3	56/-1	51/+3	-27.0/134.4	185.3
150	-24.4/-24.2	-24.2/-38.8	57.5/-2	54/0	-26.4/132.5	188.7
160	-24.4/-34	-24.2/-39	57.5/-2	55/-1	-26.5/132.8	188.2
170	-24.3/-44.1	-24.3/-39.5	56.5/-1	56/-1.5	-26.3/133.9	186.6
180	-24.1/-54.5	-24.2/-40.2	54/+2	56/-1.5	-26.5/134.9	184.9
190	-23.8/-66.4	-24.2/-41.4	50/+4	55.5/-1	-26.5/136.9	181.7
200	-23.6/-80.5	-24.1/-42.8	45/+8.5	54/+1	-26.7/139.4	177.8
210	-23.3/-96.7	-24.2/-45.6	40/+13	52/+2.5	-26.4/144.1	170.3
220	-23.3/-111.8	-24.5/-48.4	36/+17	48/+6	-25.9/146.9	164.7
230	-23.5/-123.1	-24.7/-49.6	33/+20	41/+12	-25.6/147.5	162.9
240	-23.7/-131.2	-24.7/-50.4	31/+22	36.5/+16	-25.6/148.4	161.2
250	-23.8/-137.5	-24.4/-51.6	30.5/+22.5	34.5/+19	-25.9/151.9	156.5
260	-24.1/-143.7	-24.3/-53.5	30.5/+23	34/+20	-26.0/155.2	151.3
270	-24.3/-150	-24.2/-55	31/+21.5	34.3/+19.5	-26.0/158.2	146.8
280	-24.3/-156.6	-24.1/-55	33/+19	36/+17.5	-26.1/159.3	145.7
290	-24.1/-162.9	-24.2/-48.7	36.5/+16	40/+13	-26.3/149.1	162.2
300	-23.8/-169.7	-24.2/-38.8	41/+11	46/+7.5	-26.4/132.5	188.7
310	-23.8/-177.5	-24.2/-31.1	46/+8	52/+2	-26.1/120.5	208.4
320	-24.0/174.3	-24.3/-29	49.5/+4.5	55/0	-25.9/118.8	212.2
330	-24.3/166.5	-24.4/-29.5	52/+2	56.5/-1.5	-25.8/120.4	210.1
340	-24.3/158.6	-24.3/-30	54.5/0	56.5/-1	-25.9/120.0	210.0
350	-24.4/150.7	-24.3/-31.7	56/-1	56/-1	-26.0/122.3	206.0

IMAGE FREQUENCY POWER EXTREMES IN SINGLE BALUN AS RF PHASE CHANGED:
MAXIMUMS: 165° AND 355°
MINIMUMS: 70° AND 270°

the level unbalance of the two IF signals. Data for these tests are plotted in Fig. 5. The numerical data that is listed in Table I was included to permit a more detailed phase study that is beyond the scope of this paper. Several interesting observations are made from this data.

- The IF levels were not maximum at the $\pm 90°$ LO phases, even though the image frequency level in the f_s line was at a minimum and the IF impedances were also at a minimum which would indicate maximum image frequency current flow.
- The IF levels were not in phase and even appeared to be 180° out of phase.
- Since the two mixer sections were believed to be independent, image frequency involvement was suspected due to the wide range of IF impedance values and the location of the greatest IF level variations being in the vicinity of the $\pm 90°$ LO phases, where the two image frequency vectors were 180° out of phase in each half of the ring diode quad.
- The IF impedance minimums occurred at 80° and 260° LO phase differences and the image frequency nulled in the f_s line at 70° and 270° to indicate abnormal interactions.

Equations for the IF phase differences are easily derived. Since the IF phases are the same in each mixer section diode pair, we can use diode $D1$ for IFA and diode $D4$ for IFB to avoid adding 180° for the diode symbol reversal. Refer to Fig. 4 for symbol definitions.

$$\phi_{ifa} = \phi_{s1} - \phi_{c1} \tag{1}$$

$$\phi_{ifb} = \phi_{s2} - \phi_{c2} \tag{2}$$

$$(\phi_{ifa} - \phi_{ifb}) = \phi_{s1} - \phi_{s2} - (\phi_{c1} - \phi_{c2})$$

$$\phi_{s1} = 180°, \quad \phi_{s2} = 0° \tag{3}$$

$$(\phi_{ifa} - \phi_{ifb}) = 180° - (\phi_{c1} - \phi_{c2}). \tag{4}$$

Equation (4) defines the theoretical IF phase difference for data in Table I.

2) LO in Only One Dual Balun

With the signal still connected to the single balun, only one LO was fed to each of the dual baluns. This test removes image frequency contribution from the IF output and measures the isolation between the two mixer sections. Data for this test appears in Table II. The IF level differences were 24.5 and 26.8 dB when the LO was fed to f_{c1} and f_{c2}, respectively. Good isolation is shown by these figures as well as by the high IF impedance of the mixer section that received no LO input. The IF levels are much higher with one LO input compared to the IF levels in Table I with both LO inputs.

The relative phase equations in Table II were used to calculate the relative phase of the LO carrier in each mixer section. The upper sideband (USB) is always the desired output for all tests so the IF phase is equal to the signal phase minus the LO phase. The calculated LO phase in the mixer section that had no LO input was within 4 or 5° of the input LO phase in the other mixer section. The angles appear reasonable because the IF phase difference should be 180° when two equal phase LO carriers are fed to the dual baluns.

TABLE II
SIGNAL IN SINGLE BALUN, SINGLE-FED DUAL BALUN, RING QUAD

A LO f_{c1} INPUT TO DB1 ONLY	B LO f_{c2} INPUT TO DB2 ONLY
IF A = -22 2 dBm AT +170°	IF A = -49 dBm AT +143°
IF B = -46 7 dBm AT 354°	IF B = -22 2 dBm AT 318°
Z IF A = 43 OHMS AT +12°	Z IF A = 152 OHMS AT -81°
Z IF B = 146 OHMS AT -82°	Z IF B = 42 OHMS AT +14°
IF A LEADS IF B 176°	IF A LAGS IF B 175°
IF B IS 24 5 dB BELOW IF A	IF A IS 26 8 dB BELOW IF B
USING EQUATION (4)	
(Ø IF A - Ø IF B) = 180° - ($\varnothing_{c1}$ - $\varnothing_{c2}$)	($\varnothing_{c1}$ - $\varnothing_{c2}$) = 180° - (Ø IF A - Ø IF B)
($\varnothing_{c1}$ - $\varnothing_{c2}$) = 180° - (Ø IF A - Ø IF B)	= 180° - 143° + 318°
= 180° - 170° + 354°	= 355° OR -5°
= 4°	
THUS, $\varnothing_{c1}$ IN DB1 LEADS $\varnothing_{c2}$ IN DB2 BY 4°	THUS, $\varnothing_{c2}$ IN DB2 LEADS $\varnothing_{c1}$ IN DB1 BY 5°

3) LO in Each Dual Balun, Phantom Vector Calculated in IFB

Comparing the conversion loss data in Tables I and II, it is apparent that some anomalous signal is causing the large level differences as well as the skewing of the IF phase difference angle. The anomalous signal will be called a phantom, realizing that the phantom may consist of more than one signal. Since the *IFB* mixer section LO phase was not changed in the Table I data, the effects on *IFB* in Table I can be studied by calculating the magnitude and phase of a vector that would change the single LO-fed *IFB* magnitude and phase in Table II to the changing values of *IFB* shown in Table I. This data is listed on the right-hand side of Table I. The *IFB* phase is shown referenced to the phantom phase since the phantom phase remains in a narrow range and does not follow the changing *IFA* phase. The phantom level is about 3–5 dB below the -22.2-dBm single LO-fed *IFB* side level.

4) Conclusions on Signal in Single Balun, LO in Dual Balun, Ring Quad

The level difference between the single LO-fed IF levels and those with both LO carriers applied may be understood by an inspection of Fig. 4. If an LO is applied to *DB*2, then diodes *D*2 and *D*4 will conduct each half cycle and lower the diode impedances. Diodes *D*1 and *D*3 are not driven so their impedances are high. Since the signal voltage appears between nodes *A* and *C*, we would expect that most all of the signal power would be in diodes *D*2 and *D*4. The conversion loss for the single LO-fed *IFB* side should then be the difference between the -15-dBm signal input and the -22.2-dBm *IFB* output, or 7.2 dB. Using the 90° LO phase data from Table I, the *IFB* mixer section conversion loss would be the difference between -18 dBm for the split signal power and -23.8 dBm for the *IFB* level, or 5.8 dB. This means that the image recovery is the difference between these conversion losses, or 1.4 dB. This data does not reveal the cause of the 7-dB basic mixer section conversion loss.

B. LO in Single Balun, Signal in Dual Balun

1) Signal in Each Dual Balun

The SSB balun-coupled mixer was connected with the LO in the single balun and signals in each dual balun to study its behavior without a contribution to the IF output from the image frequency. The two image frequency vectors in the *DB*1 mixer section will always be in phase between nodes *A* and *D* and between nodes *C* and *D* so the image frequency power will be fed out of the *DB*1 port. The same is true for the *DB*2 mixer section so no IF level or phase variations should be caused by the image frequency.

The phase of the signal frequency f_{s1} in *DB*1 was varied in increments of approximately 10°. The phase of the signal f_{s2} in *DB*2 remained fixed. The IF levels and impedances with their angles are plotted in Fig. 6. The numerical data is included in Table III to permit a numerical evaluation of all parameters to be made.

Several interesting observations are listed for this data.

- The IF levels changed about 1.5 dB and reached peaks and valleys near the $\pm 90°$ signal phase differences.
- The two IF levels were 180° out of phase, so that a peak of *IFA* would occur at a dip for *IFB*.
- Although the *IFB* level changed as the signal frequency f_{s1} phase was varied, the *IFB* impedance and its angle were nearly constant; however, the *IFA* impedance magnitude and angle did vary in a periodic manner.
- The angle difference between *IFA* and *IFB* was shifted from the theoretical values.
- The *IFB* phase change was about 10° indicating some dependency on the variable phase *IFA* mixer section.

The following equation may be used to calculate the IF phase difference when the signal phase difference is given:

$$(\phi_{ifa} - \phi_{ifb}) = (\phi_{s1} - \phi_{s2}) - 180°. \quad (5)$$

2) Signal in Only One Dual Balun

Feeding a signal to only one of the mixer section dual baluns should remove the image frequency contribution. The isolation between the two mixer sections would be the difference of the two IF outputs. The IF output from the section with no signal input should indicate signal frequency leakage since the LO input would equally drive both mixer sections.

Results of these tests are given in Table IV. The isolation was about 22 dB when one signal was fed to either mixer section. The phase of the signal inputs are calculated in Table IV using (5). This data shows that a feedthrough signal was present in the mixer section that had no signal input and that it was delayed 85° in that section compared to the input signal phase. This caused the feedthrough IF to lead the normally generated IF by about 95°.

Although a feedthrough IF is identified, it is 22 dB below the normal IF level and would cause no noticeable change of the normal IF level regardless of its phase.

3) Signal in Each Dual Balun, Phantom Vector Calculated in IFB

Since the phantom phase angle rotates over a 360°

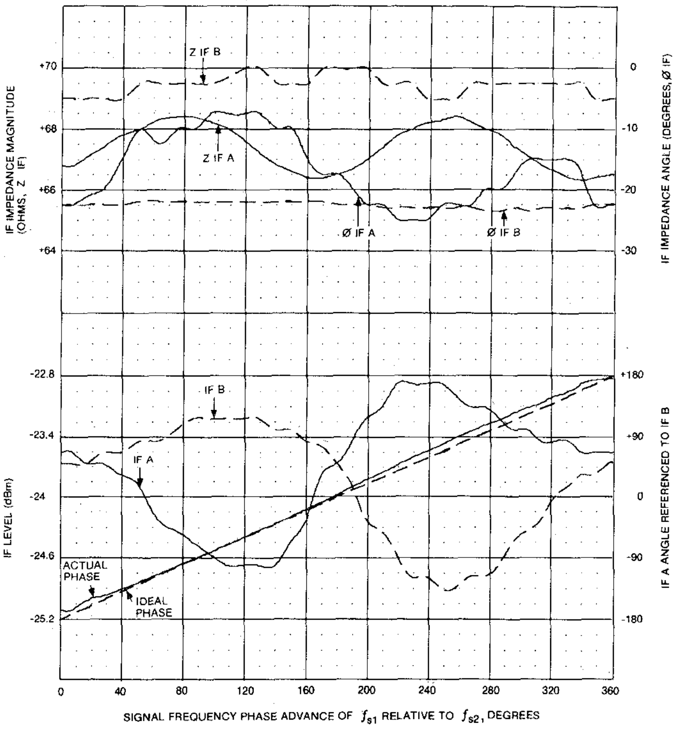


Fig. 6. Local oscillator in single balun, signal in each dual balun, ring quad.

TABLE III
LOCAL OSCILLATOR IN SINGLE BALUN, SIGNAL IN EACH DUAL BALUN, RING QUAD, PHANTOM VECTOR CALCULATED

SIGNAL FREQUENCY f_s = 6150 MHz; LO CARRIER FREQUENCY f_c = 6080 MHz
SINGLE BALUN SB INPUT: f_c AT +7 dBm
DUAL BALUN DB1 INPUT: f_{s1} AT -18 dBm
DUAL BALUN DB2 INPUT: f_{s2} AT -18 dBm
UNDISTURBED IF B MAGNITUDE AND PHASE: -23.8 dBm at 258.3°

PHASE f_{s1} REF f_{s2} DEGREES	IF A dBm/DEGREES	IF B dBm/DEGREES	72-MHz IMPEDANCE OHMS/DEGREES IF A	72-MHz IMPEDANCE OHMS/DEGREES IF B	PHANTOM VECTOR TO CHANGE IF B dBm/DEGREES	PHANTOM PHASE REF TO IF A PHASE-DEGREES
6.8	-23.6/+87.5	-23.7/-105.4	65.5/-16	69/-22.5	-35.3/186.0	98.5
16.6	-23.7/+98.3	-23.7/-104.3	65.8/-14.5	69/-22.5	-36.6/193.8	95.5
27.5	-23.7/+108.4	-23.6/-104.5	66/-13	69/-22.5	-35.4/210.1	101.7
39.2	-23.8/+119.5	-23.6/-103.4	67/-11	69/-22.5	-36.3/224.6	105.1
51	-23.9/+130.8	-23.5/-103.2	68/-10	69.5/-22	-34.9/236.7	105.9
62.7	-24.2/+142	-23.5/-102.9	67.5/-8.5	69.5/-22	-35.0/240.8	98.8
74.8	-24.3/+153.4	-23.4/-102.4	68/-8	69.5/-22	-33.9/250.3	96.9
86.3	-24.4/+164.7	-23.3/-102.0	68/-8	69.5/-22	-32.9/255.5	90.8
94.4	-24.5/+175.5	-23.3/-101.7	68.5/-9	69.5/-22	-32.9/258.3	82.8
108.3	-24.6/-173.4	-23.3/-101.6	68.5/-10	69.7/-22	-32.9/259.2	72.6
118.9	-24.6/-161.6	-23.3/-101.0	68.5/-12	70/-22	-32.9/264.7	66.3
129.3	-24.6/-150.2	-23.3/-100.4	68.5/-14	70/-22	-32.8/270.2	60.4
140	-24.6/-139.1	-23.4/-99.6	68/-16	69.5/-22	-33.6/281.1	60.2
150	-24.4/-127.7	-23.4/-98.4	68/-17	69.5/-22	-33.2/292.0	59.7
160.1	-24.2/-116.4	-23.5/-97.9	67/-18	69.5/-22	-33.8/304.1	60.5
170.3	-23.8/-104.6	-23.6/-97.2	66.5/-18	70/-22	-34.1/320.2	64.8
180	-23.7/-93.3	-23.7/-96.0	66.5/-17.5	70/-22.5	-33.6/338.2	71.5
189.6	-23.5/80.3	-23.9/-95.9	66/-16.5	70/-22.5	-33.6/4.0	84.3
199.4	-23.3/-69.3	-24.2/-95.3	65.5/-15	70/-22.5	-32.3/30.9	100.2
209.1	-23.2/-58.7	-24.3/-95.6	65.5/-13	69.5/-23	-32.0/38.5	97.2
218.9	-23/-48.6	-24.5/-96.7	65/-11	69.5/-23	-31.5/52.3	100.9
228.5	-23/-38.7	-24.7/-97.0	65/-10	69.5/-23	-30.7/56.9	97.6
238.3	-23/-29.3	-24.7/-98.3	65/-9	69/-23	-30.9/63.9	93.2
247.9	-23/-20.5	-24.8/-99.3	65.5/-8.5	69/-23	-30.5/69.1	89.6
257.5	-23.1/-11.6	-24.8/-100.8	65.5/-8	69/-23	-30.6/74.8	86.4
267	-23.2/-3.3	-24.7/-102.0	65.5/-9	69.5/-23	-31.0/79.6	82.9
276.5	-23.2/+4.8	-24.7/-103.1	66/-10	69.5/-23.5	-31.0/84.3	79.5
285.8	-23.3/+12.7	-24.6/-104.1	66/-11	69.5/-23.5	-31.4/89.9	77.2
295	-23.4/+21	-24.4/-105	66.5/-13	69.5/-23	-32.3/99.3	78.3
304.1	-23.4/+28.9	-24.3/-105.1	67/-14.5	69.5/-23.5	-32.9/103.9	75.0
313	-23.5/+37	-24.2/-104.4	67/-16	69.5/-23	-33.8/104.0	67.0
321.8	-23.5/+45.2	-24.0/-105.8	67/-17	69.5/-23	-34.6/133.5	88.3
330.9	-23.5/+53.6	-23.9/-104	67/-18	69.5/-23	-37.1/137.3	83.7
338.9	-23.6/+62.9	-23.8/-105.8	66.5/-18.5	69.5/-23	-35.2/166.2	103.3
346.9	-23.6/+68.2	-23.8/-105.7	65.5/-18	69/-22.5	-35.3/166.3	98.1
356.7	-23.6/+77.8	-23.7/-105.7	65.5/-17.5	69/-22.5	-35.0/184.5	106.7

range, the last column in Table III references the angle of the phantom vector to the *IFA* angle. We see that the phantom vector leads *IFA* from 59.7° to 106.7° with an average angle of 85.6°. The phantom level is highest near the ±90° signal phase differences with minimums near 0° and 180°.

TABLE IV
LOCAL OSCILLATOR IN SINGLE BALUN, SINGLE-FED DUAL BALUN, RING QUAD

A. SIGNAL f_{s1} INPUT TO DB1 ONLY	B. SIGNAL f_{s2} INPUT TO DB2 ONLY
IF A = -24.2 dBm AT +66.8°	IF A = -46 dBm AT 355°
IF B = -46 dBm AT +161°	IF B = -23.8 dBm AT 258.3°
Z IF A = 68.5 OHMS AT -20°	Z IF A = 68 OHMS AT -15°
Z IF B = 72 OHMS AT -17.5°	Z IF B = 69 OHMS AT -22°
IF A LAGS IF B 94.2°	IF A LEADS IF B 96.7°
IF B IS 21.8 dB BELOW IF A	IF A IS 22.2 dB BELOW IF B
USING EQUATION (5):	
(ØIF A - ØIF B) = ($Ø_{s1}$ - $Ø_{s2}$) - 180	($Ø_{s1}$ - $Ø_{s2}$) = (ØIF A - ØIF B) + 180°
OR ($Ø_{s1}$ - $Ø_{s2}$) = (ØIF A - ØIF B) + 180	= 355° - 258.3° + 180°
= 66.8° - 161° + 180	= 276.7° OR -83.3°
= 85.8°	
THUS, $Ø_{s1}$ IN DB1 LEADS $Ø_{s2}$ IN DB2 BY 85.8°.	THUS, $Ø_{s2}$ IN DB2 LEADS $Ø_{s1}$ IN DB1 BY 83.3°.

4) Conclusions on LO in Single Balun, Signal in Dual Balun, Ring Quad

With the image frequency contribution eliminated and the feedthrough level being too low to change the normal IF level, what mechanism could cause a 1.5-dB IF level variation as the f_{s1} RF input phase is changed? The average angle of 85° that the phantom vector led *IFA* is a clue. We saw in Table IV that the feedthrough IF in the mixer section with no signal input led the IF in the section with the signal input by about 95°. Referring now to Table III for a relative signal phase difference of 94.4°, we see *IFA* lags *IFB* by 82.8° and that the *IFB* level is at a maximum. The phase advance of the feedthrough IF in *IFB* is 95° compared to *IFA*. This would cause the feedthrough IF phase to be almost equal to the phase of *IFB*. This would explain why *IFB* was at its maximum level if only we knew that the feedthrough IF were of sufficient level. Referring back to Fig. 4, it is seen that diodes *D*3 and *D*4 point in the same direction between nodes *D* and *B* and that diodes *D*2 and *D*4 point in the same direction between nodes *B* and *D*. Realizing that nodes *D* and *B* are on balanced lines and that a phase difference exists between them would be cause to suspect that conduction could occur between these nodes when signals were applied to both dual baluns. This would elevate the level of the IF generated by the feedthrough signal and explain the 180° phase difference between the levels of *IFA* and *IFB*. This feedthrough explanation is complicated by the fact that with the LO in the single balun that only one of the two series connected diodes between nodes *B* and *D* would be turned on each half cycle when considering instantaneous conduction.

One may also consider the possibility of a feedthrough of the IF signal from one mixer section to the other since *IFA* and *IFB* are 180° out of phase when the two signal inputs are in phase. This would not be likely since the IF outputs are unbalanced and have a good return on the secondary balun lines.

TABLE V
RF LEAKAGE PAST RING DIODE QUAD AS DIODE LEADS ARE LIFTED

A. POWER OUTPUT FROM SINGLE BALUN AS DUAL BALUNS FED AT +3 dBm

DIODE LEADS REMOVED AT REFERENCE NODES	LO POWER OUT SINGLE BALUN (dBm)		
	f_{c1} ONLY	f_{c2} ONLY	BOTH f_{c2} AND f_{c2}
A	-16	-16	-10
B	-34	-29	-26
C	-15	-14	-8
D	-30	-34	-28
A AND B	-15	-37	-15
A AND D	-34	-14	-14
B AND C	-14	-27	-13
C AND D	-27	-13	-12
ALL CONNECTED	-37	-36	-27

B. +7 dBm LO POWER FED TO DUAL BALUN 1-MEASURE OUTPUT AT DUAL BALUN 2

DIODE LEADS REMOVED AT REFERENCE NODES	DUAL BALUN 2 OUTPUT (dBm)	INSERTION LOSS (dB)
A	-8.5	15.5
B	-39.1	46.1
C	-8.6	15.6
D	-39.0	46.0
ALL REMOVED	-30.6	37.6
ALL CONNECTED	-19.0	26.0

C. Isolation Tests Through Ring Quad

Data in Section A of Table V may be used to obtain the isolation through the ring diode quad from each dual balun to the single balun. A carrier at +3 dBm was fed to one of the dual baluns, and power out of the single balun was recorded as different diode leads were removed at the nodes as defined in Fig. 4. A monolithic diode quad was mounted in a 50-mil square package so removal of a lead on the package did not separate the diodes. Nearly 40 dB of isolation was measured with all leads connected and with only one LO applied.

Section B of Table V gives the level of leakage out of one dual balun as +7 dBm was fed to the other dual balun. Insertion loss between the dual baluns was 26 dB with all diodes connected. When either of the diode leads at nodes *A* or *C* were lifted, the loss became 15.5 dB, which shows a reasonably good return on the dual secondary lines at 6.08 GHz. Isolation between the dual baluns with no diode connected was 37.6 dB.

This data does not show any obvious isolation related problem with the balun-coupled mixer structure or with the diode connection.

IV. BRIDGE DIODE QUAD MEASUREMENTS

A. Signal in Single Balun, LO in Dual Balun

1) LO in Each Dual Balun

One solution to the low and unbalanced IF levels with the ring diode quad was to use a bridge quad, assuming that a feedthrough phenomena existed. Results of tests using a monolithic bridge quad on a 50-mil square package are plotted in Fig. 7. The numerical data is listed in Table VI. This data contains several interesting facts.

- The image frequency power out of the single balun did not reach pronounced peaks and dips and did not occur at 0°, 180°, and ±90° as expected. (The inflection points were difficult to locate because of the small variations.)
- The *IFB* angle and magnitude were affected by the LO phase change in the *IFA* mixer section.

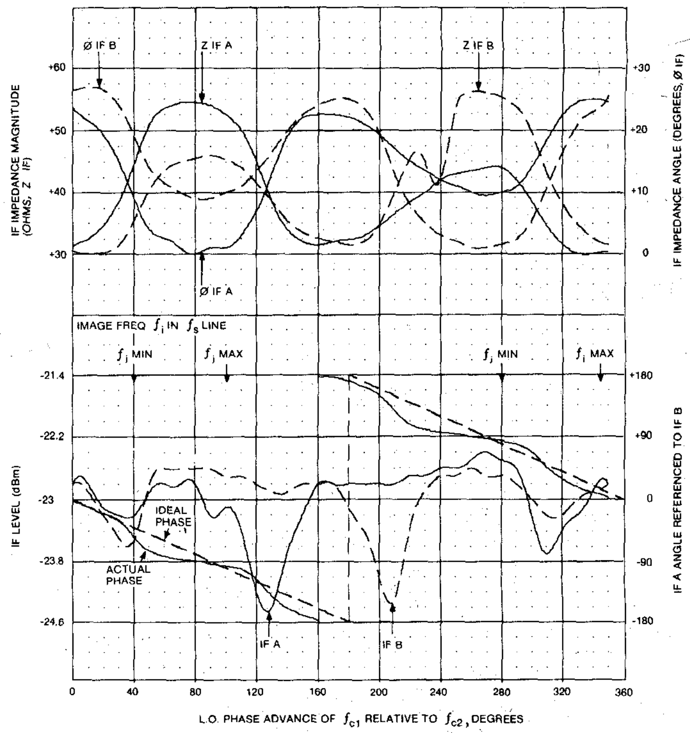


Fig. 7. Signal in single balun, local oscillator in each dual balun, bridge quad.

TABLE VI
SIGNAL IN SINGLE BALUN, LOCAL OSCILLATOR IN EACH DUAL BALUN, BRIDGE QUAD, PHANTOM VECTOR CALCULATED

SIGNAL FREQUENCY f_s = 6150 MHz; LO CARRIER FREQUENCY f_c = 6080 MHz
SINGLE BALUN SB INPUT: f_s AT -15 dBm
DUAL BALUN DB1 INPUT: f_{c1} AT +2.4 dBm
DUAL BALUN DB2 INPUT: f_{c2} AT +2.4 dBm
UNDISTURBED IF B MAGNITUDE AND PHASE: -21.3 dBm at 321.8°

PHASE f_{c1} REF f_{c2} DEGREES	IF A dBm/DEGREES	IF B dBm/DEGREES	72-MHz IMPEDANCE OHMS/DEGREES IF A	IF B	PHANTOM VECTOR TO CHANGE IF B dBm/DEGREES	IF B PHASE REF TO PHANTOM PHASE-DEGREES
0	-22.8/-45.3	-22.8/-41.9	31.5/23.5	30.5/26.5	-26.5/150.6	167.5
10	-22.8/-54	-22.9/-43.7	32.5/21.5	30/27	-26.2/153.8	162.5
20	-23.1/-63.2	-23.2/-43.4	34.7/19.2	30.2/26.5	-25.7/151.1	165.5
30	-23.2/-71.2	-23.5/-41.2	38.5/15	31.5/24	-25.2/146.3	172.5
40	-23.2/-85	-23.5/-30.8	44.5/9	35.5/19	-25.1/130.8	198.4
50	-22.9/-96.9	-22.8/-22.2	51/4	40.5/14	-25.5/110.3	227.5
60	-22.8/-105.4	-22.6/-22.6	53.5/2.5	43.5/11.5	-25.8/106.9	230.5
70	-22.8/-112.8	-22.6/-25.7	54.5/1	45/10	-26.2/111.6	222.7
80	-22.8/-119.4	-22.6/-29.7	54.5/0	45.5/9	-26.6/119.4	210.9
90	-22.8/-126.3	-22.6/-32.9	54/1	46/9	-26.9/127.1	200.0
100	-23.1/-133.6	-22.7/-36.7	52.5/1	45.3/10	-26.8/137.8	185.5
110	-23.4/-142.4	-22.7/-40.5	50/3	44/11	-26.8/147.8	171.7
120	-24.2/-158.3	-22.8/-42.3	45/7	41.5/13.5	-26.5/151.5	166.2
130	-24.4/+176	-22.9/-42.8	38.5/13	38.5/16.5	-26.3/151.9	165.3
140	-23.7/+157.3	-22.9/-43.3	34/19	35.4/20	-26.2/152.9	163.8
150	-23.2/+145.4	-22.8/-44.6	32/22	33.5/22.5	-26.4/156.7	158.7
160	-22.8/+136.2	-22.8/-46.3	31.5/22.5	32.5/24	-26.3/160.2	153.5
170	-22.8/+128.5	-22.8/-48.4	32/22.5	32/25	-26.1/164.2	147.4
180	-22.8/+120.7	-23.1/-50.4	32.3/22	31.5/25	-25.4/163.3	146.3
190	-22.8/+111.8	-23.4/-51.1	33/21	32/23.5	-25.0/160.8	148.1
200	-22.8/+103.7	-24.0/-46.4	34.5/19.3	34.7/19.5	-24.5/151.0	162.6
210	-22.8/+94.3	-24.3/-33.7	36.5/17	40/13	-24.2/137.3	189.0
220	-22.7/+85.6	-23.4/-22.6	38.5/15	45.5/8	-24.8/119.5	217.9
230	-22.7/+78.2	-22.9/-22.2	40.0/13.5	44.8/5	-25.4/112.1	225.7
240	-22.6/+71.8	-22.7/-25.2	42/12	42/3	-26.0/112.8	222.0
250	-22.6/+65.5	-22.7/-28.7	43/11	53.5/2	-26.3/119.0	212.3
260	-22.5/+58.9	-22.6/-31.4	43.5/10	55/1	-26.8/123.4	205.2
270	-22.4/+52.7	-22.7/-34.4	44/9.5	55.5/1	-26.8/131.9	193.7
280	-22.5/+46.4	-22.7/-37.5	44/10	55.3/1.5	-26.8/139.9	182.6
290	-22.6/+39	-22.8/-40.3	42/11	53.7/2.5	-26.6/146.8	172.9
300	-23.2/+26.6	-23/-41.3	38.5/14	49.3/5.5	-26.1/148.2	170.5
310	-23.7/+7.1	-23.2/-39.8	34.5/18.5	43/11	-25.7/144.7	175.5
320	-23.4/-9.7	-23.2/-39.3	31.5/22.5	38/16.5	-25.8/143.8	176.9
330	-23.2/-21.2	-23/-38.7	30/24.5	34.7/21	-26.1/142.8	178.5
340	-22.9/-29.8	-22.9/-40.2	30/25	32.5/23.5	-26.3/146.2	173.6
350	-22.8/-38.1	-22.8/-40.9	30.3/24.5	31.5/25.5	-26.6/148.2	170.9

IMAGE FREQUENCY POWER EXTREMES IN SINGLE BALUN AS RF PHASE CHANGED:
MAXIMUMS:* 120° AND 345°
MINIMUMS: 40° AND 280°

*IMAGE FREQUENCY LEVEL WAS RELATIVELY HIGH BETWEEN EQUAL LEVEL RF PHASES OF 22° AND 183° WITH A SLOW PEAK AT 102°. NONE OF THE DIPS AND PEAKS WERE PRONOUNCED.

- A lower conversion loss and almost balanced IF levels were obtained at the ±90° LO phases.

TABLE VII
SIGNAL IN SINGLE BALUN, SINGLE-FED DUAL BALUN, BRIDGE QUAD

A LO f_{c1} INPUT TO DB1 ONLY	B LO f_{c2} INPUT TO DB2 ONLY
IF A = -21 3 dBm AT 348 5°	IF A = -37 3 dBm AT +69 2°
IF B = -39 dBm AT +92 7°	IF B = -21 3 dBm AT 321 8°
Z IF A = 35 5 OHMS AT +20 5°	Z IF A = 144 OHMS AT -66 5°
Z IF B = 142 OHMS AT -72°	Z IF B = 345 OHMS AT +23 5°
IF A LAGS IF B 104 2°	IF A LEADS IF B 107 4°
IF B IS 17 7 DB BELOW IF A	IF A IS 16 dB BELOW IF B
USING EQUATION (6)	
(Ø IF A - IF B) =-($Ø_{c1}$ - $Ø_{c2}$)	
$Ø_{c1}$ - $Ø_{c2}$ = Ø IF B - Ø IF A	$Ø_{c1}$ - $Ø_{c2}$ = Ø IF B - Ø IF A
= 92 7° - 348 5°	= 321 8° - 69 2°
= 255 8° OR 104 2°	= 252 6° OR -107 4°
THUS, $Ø_{c1}$ IN DB1 LEADS $Ø_{c2}$ IN DB2 BY 104 2°	THUS, $Ø_{c2}$ IN DB2 LEADS $Ø_{c1}$ IN DB1 BY 107 4°

- The IF impedance magnitude spread was larger with the bridge quad than the ring quad.
- The IF impedance magnitude maximums and angle minimums occurred at the $\pm 90°$ LO phases.

The IF phase difference equation will use diodes $D3$ and $D4$ to avoid adding 180° for the diode polarity symbol reversal. (Remember that the diode symbol for $D3$ points toward node D in the bridge quad.)

$$(\phi_{ifa} - \phi_{ifb}) = -(\phi_{c1} - \phi_{c2}). \qquad (6)$$

2) LO in Only One Dual Balun

Data for this test is given in Table VII. The feedthrough IF levels are now higher with losses of 17.7 and 16 dB. The feedthrough LO carrier is seen to lag the input LO by 104.2° and 107.4° as calculated from the relative phase equations. The feedthrough IF leads the IF with the LO input by about 105°. Of particular importance is the IF impedance magnitude of over 140 Ω in the feedthrough section IF. This means that the bridge quad effectively blocked the LO power leak-through that prevented the diodes from being turned on, but this is not consistent with the feedthrough loss of 16 dB.

3) LO in Each Dual Balun, Phantom Vector Calculated in IFB

We can look at this case the same way that was done for the ring quad. Again referring to Fig. 4 using the bridge quad, it is seen that with only one LO carrier the side with no LO should have a negligible amount of signal power considering its high impedance, even though it has the same signal voltage as the section with the LO input. The IF level for *IFB* from Table VII is -21.3 dBm, which combined with the total signal input of -15 dBm would give a conversion loss of 6.3 dB. The value of *IFB* from Table VI at a 90° LO phase is -22.6 dBm, which combined with the split signal power of -18 dBm would give a conversion loss of 4.6 dB. This means that the image recovery power is the difference of 6.3 and 4.6-dB conversion losses or 1.7 dB. This test setup is slightly more lossy than typical SSB balun-coupled mixers with the bridge quad since the latter has a typical 4.5-dB conversion loss that includes the 90° IF hybrid.

4) Conclusions on Signal in Single Balun, LO in Dual Balun, Bridge Quad

The bridge quad in the SSB balun-coupled mixer presents an interesting phenomena. The change in the *IFB* level in Table VI from its minimum value of -24.3 dBm at 210° LO phase difference to its maximum value of -22.6 dBm is 1.7 dB, which is the exact value calculated for the image frequency power recovery. No feedthrough mechanism or any other peculiar behavior is then identified.

The most unusual behavior seen in this data is the high IF impedances that were measured at the $\pm 90°$ LO phase differences where the conversion losses were at a minimum. This condition is identified as an open-circuited termination of the image frequency voltage. Ideally, there should be no coupling to the image frequency voltage in either dual balun, and cancellation should occur in the single balun. Although the levels observed for the image frequency out of the single balun changed several decibels as the phase shift of f_{c1} was changed, most of the levels were low and did not show distinct maximums and minimums. It is also interesting to note that the 6.3-dB undisturbed *IFB* conversion loss previously calculated agrees exactly with the difference between the split signal power of -18 dBm and the least level of *IFB* of -24.3 dBm. This says that the image frequency power recovery would account for the full range of level variations for *IFB*. The phantom vector therefore represents the image frequency vector that alters the magnitude and phase of the *IFB* vector.

The image frequency voltage being open-circuited is certainly evident by the high IF impedances at the $\pm 90°$ LO phase positions, by the rather sudden way the conversion loss drops at the *IFA* and *IFB* sides that could be caused by the return of the image frequency power to the single balun line, and by the large bandwidths that the SSB balun-coupled mixed has demonstrated (Hallford [7] reports more than 20-dB image rejection for the mixer in [4] with its 90° RF hybrid from 4700 to 7500 MHz.) It is not known that any other mixer can be changed from a shorted image frequency voltage to an open-circuited image frequency voltage merely by changing the polarity sequences of the diode quad. Note that this impedance change occurs without altering the circuit impedance, and is accomplished only by closing the image frequency current path in the ring diode quad or by interrupting the image frequency current path in the bridge quad.

B. LO in Single Balun, Signal in Dual Balun

1) Signal in Each Dual Balun

The LO was fed to the single balun to remove the image frequency power influence on the IF output levels. This data is plotted in Fig. 8 with the numerical data appearing in Table VIII. Several observations of unusual behavior may be made.

- The *IFA* and *IFB* levels varied over a 1.5-dB range and were 180° out of phase.

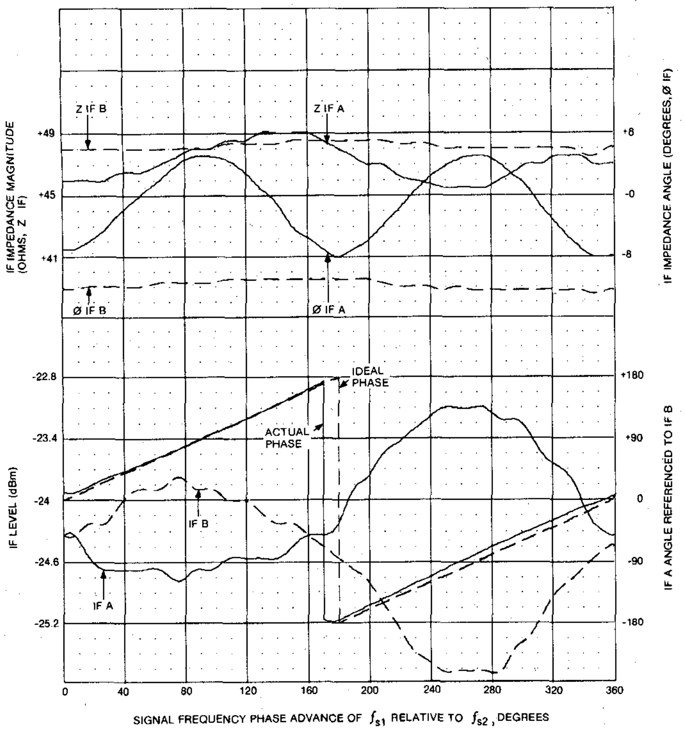


Fig. 8. Local oscillator in single balun, signal in each dual balun, bridge quad.

TABLE VIII
LOCAL OSCILLATOR IN SINGLE BALUN, SIGNAL IN EACH DUAL BALUN, BRIDGE QUAD, PHANTOM VECTOR CALCULATED

SIGNAL FREQUENCY f_s = 6150 MHz; LO CARRIER FREQUENCY f_c = 6080 MHz
SINGLE BALUN SB INPUT: f_c AT +7 dBm
DUAL BALUN DB1 INPUT: f_{s1} AT -18 dBm
DUAL BALUN DB2 INPUT: f_{s2} AT -18 dBm
UNDISTURBED IF B MAGNITUDE AND PHASE: -24 dBm at 234.4°

PHASE f_{s1} REF f_{s2}	IF A	IF B	72-MHz IMPEDANCE OHMS/DEGREES		PHANTOM VECTOR TO CHANGE IF B	IF A PHASE REF TO PHANTOM PHASE-
DEGREES	dBm/DEGREES	dBm/DEGREES	IF A	IF B	dBm/DEGREES	DEGREES
6.8	-23.3/-118.5	-23.3/-130.2	46.0/-7	48/-12.5	-31.0/205.5	36.0
16.6	-23.5/-108.4	-23.2/-129.8	46.0/-6	48/-12	-30.6/210.5	41.1
27.5	-23.6/-97.7	-23.2/-129.6	46.0/-4.5	48/-12	-30.6/211.5	50.8
39.2	-23.6/-87.1	-23.0/-129.2	46.5/-2	48/-12	-29.7/217.2	55.7
51.0	-23.6/-75.3	-22.9/-128.0	46.5/0	48/-12	-29.3/223.7	61.0
62.7	-23.6/-63	-22.9/-127.4	47.0/+2	48/-11.5	-29.3/226.3	70.7
74.8	-23.7/-51.4	-22.8/-126.6	47.5/+4	48/-11.5	-28.9/230.2	78.4
86.3	-23.6/-40	-22.9/-125.4	48.0/+5	48/-11.5	-29.4/235.2	84.8
97.4	-23.6/-28.4	-22.9/-125.4	48.0/+5	48/-11.5	-29.4/235.2	96.4
108.3	-23.5/-16.9	-23.0/-124.3	48.5/+4.5	48.3/-11	-29.8/240.7	102.4
118.9	-23.5/-5.2	-23.0/-124.0	48.5/+3	48.3/-11	-29.8/242.1	112.7
129.3	-23.5/+5.0	-23.1/-123.5	49.0/+1	48.3/-11	-30.3/245.5	119.5
140.0	-23.5/+17.4	-23.2/-123.1	49.0/-1	48.3/-11	-30.8/249.0	128.4
150.0	-23.4/+28.8	-23.2/-122.7	49.0/-4	48.5/-11	-30.7/251.2	137.6
160.1	-23.3/+40	-23.3/-122.4	49.0/-5.5	48.5/-11	-31.3/255.1	144.9
170.3	-23.3/+51.3	-23.4/-121.9	48.5/-7	48.5/-11	-31.8/261.3	150.0
180.0	-23.2/+62.2	-23.5/-121.6	48.0/-8	48.5/-11	-32.4/267.6	154.6
189.6	-22.9/+73.2	-23.6/-121.1	47.5/-7	48.5/-11	-32.9/277.2	156.0
199.4	-22.8/+84	-23.7/-121.0	47.0/-6	48.5/-11	-33.6/286.1	157.9
209.1	-22.6/+94.2	-23.9/-121.0	47.0/-4	48.5/-11.5	-34.7/310.8	143.4
218.9	-22.5/+104.8	-24.1/-121.6	46.3/-2	48.3/-12	-35.3/344.7	120.1
228.5	-22.4/+114.8	-24.3/-122.0	46.0/0	48.3/-12	-34.4/13.8	101.0
238.3	-22.3/+123.7	-24.4/-122.6	45.8/+2	48.3/-12	-33.9/26.2	97.5
247.9	-22.2/+134	-24.5/-123.8	45.5/+3.5	48/-12.5	-33.4/40.0	94.0
257.5	-22.2/+143.4	-24.5/-124.7	45.5/+4.5	48/-12	-33.5/47.0	96.4
267.0	-22.2/+152.2	-24.5/-126.1	45.5/+5	48/-12.5	-33.6/58.4	93.8
276.5	-22.2/+160.7	-24.5/-127.0	45.5/+5	48/-12.5	-33.5/65.6	95.1
285.8	-22.3/+169.3	-24.4/-127.9	46.0/+4	48/-12.5	-34.1/76.8	92.5
295.0	-22.3/+177.3	-24.3/-129.2	46.5/+2.5	48/-12.5	-34.4/94.9	82.4
304.1	-22.4/-174.6	-24.2/-129.6	47.0/+1	48/-12.5	-34.8/109.0	76.4
313.0	-22.6/-166.7	-24.0/-130.2	47.0/-1.5	48/-12.5	-34.9/142.1	51.2
321.8	-22.7/-158.4	-23.8/-130.8	47.5/-3.5	48/-12.5	-33.8/168.6	33.0
330.9	-22.8/-150.2	-23.7/-131.3	47.5/-5.5	48/-12.5	-33.0/176.2	33.6
338.9	-23.0/-141.7	-23.6/-131.2	47.5/-7	47.8/-12.5	-32.5/184.8	33.5
346.9	-23.2/-136.3	-23.5/-130.3	47.0/-8	47.5/-13	-32.2/196.5	27.2
356.7	-23.3/-127.4	-23.4/-130.2	47.0/-8	48/-12.5	-31.6/201.8	30.8

- The measured IF angles showed some disagreement with the theoretical or ideal angles.
- Although the *IFB* levels changed as much as the *IFA* levels, the *IFB* complex impedance did not change even though the *IFA* complex impedance did change.

TABLE IX
LOCAL OSCILLATOR IN SINGLE BALUN, SINGLE-FED DUAL BALUN, BRIDGE QUAD

A. SIGNAL f_{s1} INPUT TO DB1 ONLY	B. SIGNAL f_{s2} INPUT TO DB2 ONLY
IF A = -23.6 dBm AT 221.4°	IF A = -45 dBm AT 156.2°
IF B = -44.7 dBm AT +136.8°	IF B = -24 dBm AT 234.4°
Z IF A = 48 OHMS AT -6.5°	Z IF A = 48 OHMS AT -2°
Z IF B = 51.5 OHMS AT -5.5°	Z IF B = 48 OHMS AT -12°
IF A LEADS IF B 84.6°	IF A LAGS IF B 78.2°
IF B IS 21.1 dB BELOW IF A	IF A IS 21 dB BELOW IF B
USING EQUATION (7):	
(Ø IF A - Ø IF B) = ($Ø_{s1}$ - $Ø_{s2}$)	($Ø_{s1}$ - $Ø_{s2}$) = (Ø IF A - Ø IF B)
s1 - s2 = 221.4° - 136.8°	= 156.2° - 234.4°
= 84.6°	= 78.2°
THUS, $Ø_{s1}$ IN DB1 LEADS $Ø_{s2}$ IN DB2 BY 84.6°.	THUS, $Ø_{s2}$ IN DB2 LEADS $Ø_{s1}$ IN DB1 BY 78.2°.

- The IF impedance magnitudes were close to 50 Ω to easily terminate a 90° IF hybrid, but this would be offset by the large IF level unbalance.
- *IFA* minimum conversion loss was 4.2 dB, whereas *IFB* minimum conversion loss was 4.8 dB.

The relative phase equation that relates the IF and signal phase difference is as follows:

$$(\phi_{ifa} - \phi_{ifb}) = (\phi_{s1} - \phi_{s2}). \tag{7}$$

2) Signal in Only One Dual Balun

The isolation properties of the bridge diode connection may be studied by feeding a signal to only one of the dual baluns. Data for this test is given in Table IX. A summary of the results from Table IX follows.

- Isolation to the mixer section with no signal was 21 dB.
- The feedthrough IF to the section not fed lagged the IF with the signal input by 84.6° and 78.2°. The relative phase calculations show this to be caused by a feedthrough signal that lags the input signal by 84.6° and 78.2°.
- The IF impedances of the two mixer sections were almost equal.

3) Signal in Each Dual Balun, Phantom Vector Calculated in IFB

Since the phase of the phantom vector rotates a full 360°, the phase of the changing *IFA* vector was referenced to the phantom phase in the last data column in Table VIII.

4) Conclusions on LO in Single Balun, Signal in Dual Balun, Bridge Quad

From Table VIII, it is noted that *IFA* always leads the phantom by an angle from 30.8° to 157.9°. A feedthrough IF was listed in Table IX that lagged the normal IF by about 85°. This means that when *IFA* is 85° ahead of *IFB* that the feedthrough IF from *IFA* should be in phase with *IFB*. Looking at Table VIII for a signal phase difference of 86.3°, we see that *IFA* leads *IFB* by 85.4° and that *IFB* is indeed at a maximum level of −22.9 dBm, ignoring the

IFB level of −22.8 dBm at a signal phase difference of 74.8°. This data shows that a feedthrough signal is responsible for both the *IFA* and *IFB* level variations.

V. Conclusions on All Measurements

Using the ring quad in the SSB balun-coupled mixer was shown to cause an unbalance in the phase and magnitude of the two mixer section IF outputs when the signal was fed to the single balun. A feedthrough of the RF signals from one mixer section to the other via the pair of two series diodes connected between the balun primaries was responsible for the IF output unbalance and also caused an increase in the mixer conversion loss. The RF signal feedthrough phenomena could not be corrected by providing a lower impedance on the balun secondary lines through the use of quarterwave-long open-circuited stubs. Connecting the diodes between the mixer section with opposing polarities, as provided by the bridge quad, was the easiest means to block the RF signal feedthrough path.

The bridge diode quad improved the balance of the IF outputs and lowered the individual mixer conversion loss from 7 to 6 dB. This high loss for both types of diode quads is not fully understood. The balun structures are not inherently lossy since two baluns joined together to form the IF rejection filter earlier described have a total RF loss of 0.3 dB. The balun line widths were optimized for minimum return loss with a 50-Ω chip resistor joined to the balun secondary output terminals. The resistance of the diodes is approximately 8 Ω so they should not be responsible for the high conversion loss. Proper matching to the diodes is indicated by a return loss into the single balun of greater than 26 dB. Higher LO drive levels do not appreciably lower the conversion loss. It could be reasoned that the high conversion loss may be caused by the signal input power flowing through two diodes in series with only one of the diodes being turned on at any given time by an instantaneous conduction from the LO power.

The measured data revealed a unique relationship between the image frequency termination and the diode polarity connections. The image frequency vector from each mixer section are 180° out of phase between opposite terminals of the diode quad. Mounting the ring quad between these terminals causes the image frequency current to flow around a closed path to represent a low impedance to the image frequency voltage, or a "short circuit" to the image frequency. The bridge quad interrupts the image current and presents a high impedance to the image frequency voltage, or an "open circuit" to the image frequency. This phenomena is validated by the magnitude of the IF impedances and by the amount of image recovery. The image recovery for the ring quad was 1.4 dB and for the bridge quad it was 1.7 dB. The greatest image recovery should occur when the image frequency voltage is open-circuited because no conversion loss is required to recover the power.

The extensive amount of data on the irregular behavior of the balun-coupled mixer should not be allowed to discredit its performance. Both types of diode quads showed a remarkable stability in the amplitude and group delay response of the IF output with changes of RF frequency and LO power level variations, which has been a limitation to other SSB mixers we have evaluated. Both types of diode quads have their distinct advantages. For instance, the low IF impedance of the ring quad may be preferred to the higher IF impedance of the bridge quad. The remarkable immunity of the SSB balun-coupled mixer to RF frequency and LO power variations is fully described in [7].

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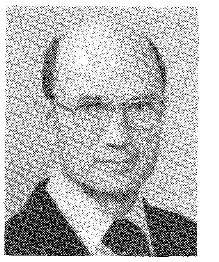

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