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# Low Cost Mixer for the 10.7 to 12.8 GHz Direct Broadcast Satellite Market

## Application Note 1136

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### Introduction

The wide bandwidth requirement in DBS satellite applications places a big performance demand on the individual components in the low noise block downconverter. This application note describes a low cost, wide bandwidth passive mixer for 10.7 to 12.8 GHz DBS applications with low LO drive requirements. The mixer uses the Hewlett-Packard HSMS-8202 dual mixer diode in the SOT-23 package.

### DBS Frequency Conversion Scheme

Considering the broad RF bandwidth requirements of many of the DBS services such as Astra, the 10.7 to 12.7 GHz RF band must be downconverted to an IF which is generally 950 to approximately 2300 MHz. Attempting to translate the entire 2 GHz of RF bandwidth down to a 1.35 GHz wide IF does have its challenges. Most important besides the bandwidth issue is image rejection and LO radiation back out the antenna port of the LNA. A typical LNB uses two LO frequencies, one at 9.75 GHz and one at 10.6 GHz. With a 9.75 GHz LO, the 10.7 to 12.1 GHz band will be downconverted to 950 to 2350 MHz. With the 10.6 GHz LO,

the 11.7 to 12.8 GHz band down-converts to 1100 to 2200 MHz.

### Mixer Topologies

A very common mixer topology is the 90 degree branch line hybrid as shown in Figure 1.

The hybrid is a 4 port device with the LO and RF being fed into two adjacent ports and the two mixer diodes which are connected in series are connected to the remaining two ports. Each section of the square is 90 degrees in length. The IF is extracted from the junction of the two diodes. Proper filtering of the RF and LO is needed at the IF port. The operation of this mixer is covered in an existing Hewlett-Packard application Note AN-1052 [1]. This mixer provides good input VSWR at the LO and RF ports but has limited bandwidth and port to port isolation.

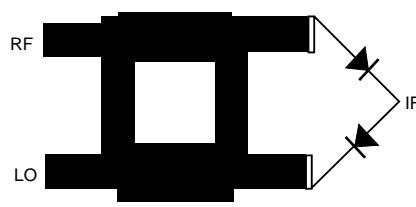
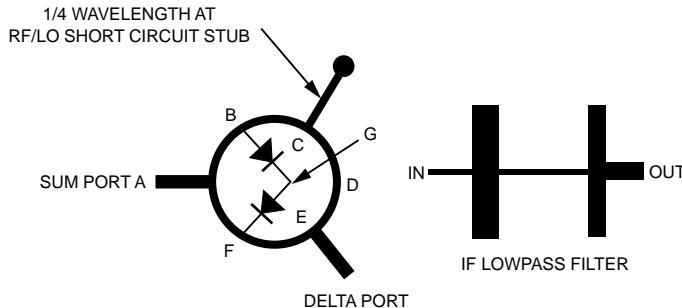


Figure 1. Branch Line Hybrid Mixer

Another mixer configuration is the hybrid ring mixer which is sometimes called a rat race mixer. According to Maas [2], the rat race mixer has a wider bandwidth as compared to other mixer types, making it appropriate for the very wide bandwidth of the typical DBS system. A typical rat race mixer is shown in Figure 2.

The Rat Race Mixer is comprised of six quarterwave length  $70 \Omega$  transmission lines in a circle. Each transmission line is 90 degrees in length for a total perimeter of 540 degrees or 1.5 wavelength.

The operation of the hybrid ring is as follows. A signal incident at port A is divided into two paths. The signals that arrive at ports B and F are both delayed by 90 degrees but arrive in phase and hence the name Sum port. A signal incident at the E port travels around the ring with a 90 degree delay to port F and a 270 degree delay to port B. The signals that arrive at ports B and F are out of phase when fed from port E and hence port E is called the Delta port. Normally the mixer diodes are driven with the LO fed out of phase through the delta port and the RF is fed in-phase at the Sum port.



**Figure 2. Rat Race Mixer**

The rat race mixer also provides port to port isolation. A signal incident at port A will split and the signals that arrive at port E will be out of phase and cancel providing some isolation. In a similar manner a signal incident at port E will divide and arrive again out of phase at port A providing isolation. This isolation could be in the 10 to 30 dB range. Best isolation will occur at the frequency where each segment of the rat race mixer is 90 degrees in length. As the frequency is varied from the nominal design frequency, the isolation and basic mixer performance will get worse.

Having a good handle on the best ports for both the RF and LO, attention must now be turned to the IF port. The IF can actually be extracted from the mixer in several locations. Based on the phasing through the ring, it appears that port C would offer some RF to IF or LO to IF isolation. This may suggest that port C may be a good choice. Some textbooks suggest the use of port D for the IF but based on the phase relationships, it does not appear to be the optimum port. Another option is to pull the IF at the junction of the two mixer diodes at point G. This point is usually RF and LO grounded. If one were to use an open circuited stub at this point to place point G at a low potential at

the RF and LO frequencies, then the IF could still be extracted at this point. The mixer in this application makes use of this method. A four section low pass filter provides an additional 25 to 30 dB attenuation of both the RF and LO frequencies at the IF port.

A quarterwave length (@ RF and LO) short circuited stub placed at port C places the ring coupler at a low impedance at the IF. According to the theory, this stub should improve conversion efficiency but was found to be unnecessary with the design presented in this application note.

## Mixer Design

### Ring Coupler

The first item to design is the ring coupler. As discussed in the previous section, the wide RF bandwidth is downconverted to the IF in two segments. The actual frequency at which the band is split depends on a couple of factors. One is image rejection of available RF filtering and the other is LO to RF port radiation. Image rejection is determined primarily by the bandpass filter at the RF port of the mixer. Radiated LO from the LNA antenna port is influenced by several factors. The first is the reverse gain of the LNA at the LO frequency. The second would be the LO to RF port isol-

ation of the mixer. The third factor is the rejection of the LO frequency by the RF port filtering. Considering that the lowest RF frequency is 10.7 GHz and one of the suggested LO frequencies is 10.6 GHz, suggests that the RF port filtering will be a challenge. Therefore, it is best to design the mixer for best performance at the 10.6 GHz LO frequency. The ring coupler was designed to be 540 degrees in length at 10.6 GHz. The characteristic impedance of the transmission line is  $70\ \Omega$ .

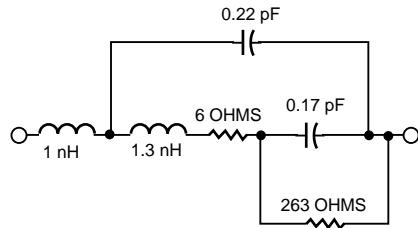
### Diode Match

For low cost, the Hewlett-Packard HSMS-8202 in a surface mount SOT-23 plastic package containing two matched Schottky diodes was chosen for the application. Although a plastic packaged part has greater parasitic elements than a typical ceramic package, the parasitics can be tuned out.

The  $70\ \Omega$  characteristic impedance of the ring coupler dictates that each port be  $50\ \Omega$  for best performance. Typically the diodes are connected directly to ports B and F with no matching networks. Considering the bandwidth requirement of the mixer, a matching network was designed within the space confines of the ring coupler. The challenge is to match each diode as best as possible from 9.75 GHz (the lowest LO frequency) to 12.8 GHz (the top of the RF band).

The model for each diode in the SOT-23 package is shown in Figure 3.

The equivalent circuit takes into account the nominal +7 dBm LO drive and the package parasitics. Each HSMS-8202 consists of two of these diodes in series with the anode of one diode and the

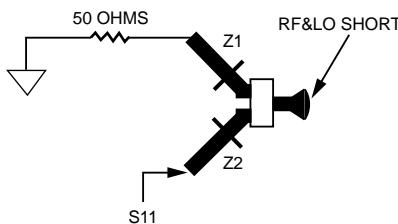


**Figure 3. Diode Equivalent Circuit**

cathode of the second diode connected together and brought out to a third terminal. It is this third terminal that will be used as the IF port. For best mixer performance, the IF port of the diode should be presented with a low impedance at the RF and LO frequencies. This low impedance keeps the RF and LO signals from propagating out the IF port and consequently making conversion loss worse. The low impedance is accomplished by placing an open circuited stub on the printed circuit board at the IF terminal of the diode. A trapezoidal open circuited stub is used in the design and its length and angle were optimized using EESOF Libra.

A small length of transmission line was used to provide a better impedance match to the diodes over the 9.75 to 12.8 GHz frequency range. Its length and width were optimized with EESOF Libra. The HSMS-8202 and its associated matching networks are shown in Figure 4.

With the LO being injected into the Delta port, the phase of the voltages present at the diodes is out of phase but since the diodes are connected to the ring coupler in opposite orientation from each other they can be viewed as being turned on simultaneously. This means that the model for the diode package and the matching network must assume that the diodes are on at the same time and



**Figure 4. HSMS-8202 and Matching Networks**

should be modeled as such.

As shown in Figure 4, both diodes share the trapezoidal open circuited stub as a common RF and LO short. Each diode leg must then be matched individually to as near  $50\ \Omega$  as possible. Since both diodes are identical, then it follows that identical matching networks be used.

The circuit shown in Figure 4 was optimized using EESOF Libra. One of the diodes and its corresponding matching structure is terminated in  $50\ \Omega$  with the other leg used by the simulator to determine best match. Both Z1 and Z2, which are identical, and the trapezoidal open circuited stub were optimized for best return loss, S11. The fact that the entire matching networks and diodes must fit within the ring coupler does limit the physical size of the networks. According to EESOF Libra, S11 optimized at approximately 10 dB from 9.75 to 12.8 GHz.

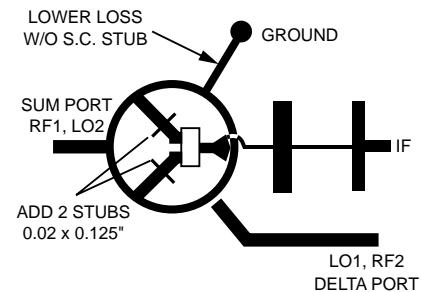
The resultant matching network Z1 and Z2 are series transmission lines of  $0.035"$  width by  $0.200"$  in length. The additional stubs that are placed on Z1 and Z2 were later determined empirically to improve conversion loss. They are  $0.020"$  by  $0.120"$  and placed approximately  $0.140"$  from the ring

coupler. These dimensions are for a dielectric material of  $0.020"$  thickness and a dielectric constant of 2.5. Complete artwork is contained in Figure 10 at the end of this application note.

## Construction

The completed mixer is shown in Figure 5. The Sum port is dc connected to the ring coupler. The Delta port is ac coupled with a  $1\ pF$  chip capacitor at the ring coupler. The small value chip capacitor should help reduce IF leakage out the Delta port when used for LO injection.

A small wire is used to dc couple in the IF low pass filter. In actual systems, the connection from the mixer to the IF is quite often through a feedthrough pin to an adjacent printed circuit board where the IF amplifiers are located. Another option is a zero ohm resistor across the ring coupler.



**Figure 5. Ku Band Mixer using HSMS-8202**

## Performance

Conversion loss was initially measured using the Delta port as the LO port. As was later determined, the mixer had slightly less conversion loss at the low end of the frequency range when the Sum port was driven with the LO. The performance of both configurations is shown in Figures 6 and 7.

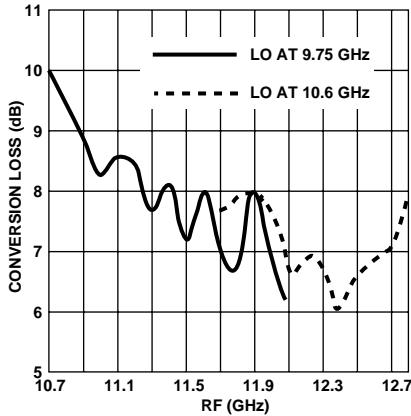


Figure 6. Conversion Loss with +1 dBm LO @ Delta Port

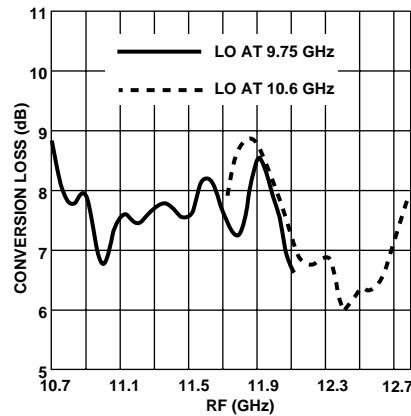


Figure 7. Conversion Loss with +5 dBm LO @ Sum Port

+1 dBm LO was found to produce minimum conversion loss when the Delta port was the LO port. When injecting the LO into the Sum port, it was found that +5 dBm was required to produce minimum conversion loss.

Based on the frequency of minimum conversion loss and the performance at the band edges, it appears that the ring may be centered somewhat high in frequency. Considering that the ring and diode matching networks must cover 9.75 to 12.7 GHz, a nearly 3 GHz of bandwidth, the perfor-

Table 1. LO to RF and LO to IF Isolation

Configuration	LO Frequency (GHz)	LO to RF Isolation (dB)	LO to IF Isolation (dB)
LO in Sum Port @ +5 dBm	9.75	25.4	40.3
	10.6	30.5	37.8
LO in Delta Port @ +1 dBm	9.75	25.8	48.0
	10.6	32.5	46.0

mance can still be considered very good. The improved higher end performance might well offset the usual gain and noise figure rolloff of the LNA.

LO to RF port and LO to IF port isolation was tested for both configurations and the results are shown in Table 1.

Based on the LO to RF isolation data, it appears that the ring coupler was optimized properly for 10.6 GHz rather than 9.75 GHz. Comparing the isolation data and the previous conversion loss data may suggest that the center frequency is even higher than 10.6 GHz. The next iteration should be centered somewhat lower in frequency to improve the low end RF performance.

The LO to IF isolation was measured with a four section low pass filter at the IF port. The low pass filter with its inductive input places a high impedance to the RF and LO at the junction of the mixer diodes and the trapezoidal bypass capacitor. As the data shows, the basic mixer has better LO to IF isolation when the LO is fed into the Delta port.

Conversion loss versus LO power was measured for both mixer schemes. For test purposes, the RF frequency is 12.2 GHz and the LO frequency is 10.6 GHz. The per-

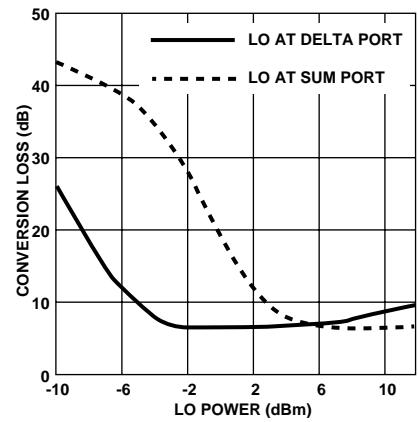


Figure 8. Effect of LO Power on Mixer Performance

formance is shown in Figure 8. Normally, one would not expect as radical a difference in performance between feeding the Sum or the Delta port. Further investigation showed that the Delta port has a very good return loss as compared to the Sum port when used as the LO port. The mixer was originally optimized for best conversion loss when the Delta port was used to feed the LO. The resultant bench tuning optimized the mixer for delta port LO feed with the RF at the Sum port. The Delta port return loss with a 10.6 GHz LO measured 11.5 dB at a +1 dBm LO and 14.7 dB at +5 dBm LO power. The same measurement on the Sum port revealed return losses of only 2 dB or slightly less. Converting the return loss to a resultant mismatch loss suggests at least a 4.2 dB - 0.3 dB = 3.9 dB

potential difference in drive level required. This correlates well with the 4 dB difference observed in LO drive requirements for feeding the Sum versus the Delta port.

### Dual Channel LNB

The mixer may be used as part of a dual channel LNB as shown in Figure 9. A power divider is used to feed the LO to both mixers. Approximately +5 to +6 dBm LO power is required at the input to the power divider. This insures adequate LO drive to each mixer.

The most important parameter of the two channel mixer is the channel to channel isolation. Poor channel to channel isolation results in the appearance of co-channel interference in the received TV signal. The channel to channel isolation is influenced by the LO power divider and its ability to couple energy from one mixer to the other. From the system point of view, the concern is how far down in amplitude will the RF1 signal be when it cross couples from channel 1 over into channel 2 through the LO power divider and shows up as undesired downconverted IF output at the IF2 port.

The RF to LO isolation has been measured at approximately 25 dB. A well designed LO power divider may have only 15 dB of port to port isolation. Therefore, the undesired RF1 signal that is incident on the LO port of the channel 2 mixer is 40 dB below the normal RF1 or RF2 signal level. The question that remains is how well does this undesired RF1 signal (which is now at the same port as the normal LO signal at channel 2 mixer) downconvert to an IF signal at the IF2 port?

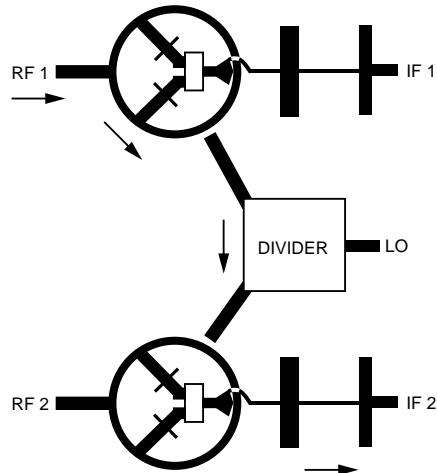


Figure 9. Dual Channel Downconverter

Table 2. Conversion Loss with RF and LO incident on same port

Mixer Configuration	LO Frequency (GHz)	RF Frequency (GHz)	Conversion Loss (dB)
RF and LO @ Delta Port	9.75	10.7	25
	9.75	11.7	27
	10.6	12.0	24
	10.6	12.8	24
RF and LO @ Sum Port	9.75	10.7	23
	9.75	11.7	20.5
	10.6	12.0	23
	10.6	12.8	23

The mixer was tested for this situation by coupling in a -20 dBm RF signal (simulating the interfering signal from the adjacent channel mixer) along with the normal +1 dBm LO into the Delta port of the mixer. Conversion loss was measured. The results are shown in Table 2 for both mixer configurations.

The mixer exhibits from 10 to 15 dB greater conversion loss when the RF and LO are fed into the same port. Slightly greater conversion loss is obtained when the LO is injected into the Delta port.

Therefore, the interfering signal from the adjacent channel will be at a level approximately 50 to 55 dB below the desired signal at the IF output port.

The mixer provides this type of rejection for the same reason that a balanced mixer provides AM LO noise cancellation. Normally the diodes are LO driven from the Delta port which causes the LO voltage to have a 180 degree phase difference at the two diodes. Since the diodes are reversed, the junction conductance waveforms across each diode (generated as a

result of the large-signal termed the LO) are in phase. With the RF fed into the Sum port, the RF voltage is in phase at the diodes. Since the junction conductance waveforms are in phase along with the RF voltage, then the IF voltages must also be in phase. The IF voltages add and produce the desired IF output. If there is AM noise riding on the LO signal or any other small-signal also incident on the LO port, the situation changes. The undesired small-signal, which enters the Delta port, arrives at the diodes out of phase and therefore cancels at the IF port.

## Conclusion

The HSMS-8202 has been shown to produce very good performance in DBS applications when used in a rat race type mixer. The mixer also provides a good solution for dual channel systems.

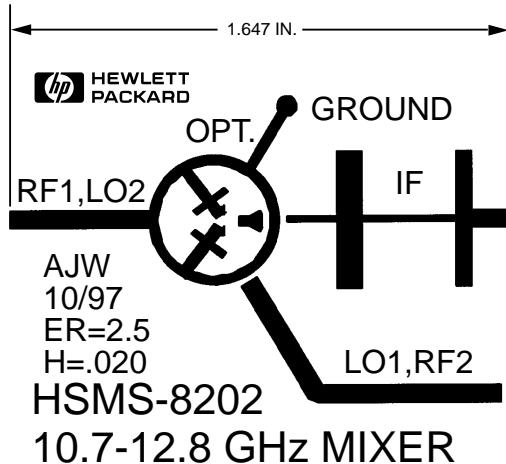


Figure 10. Artwork for DBS Mixer

## References

- [1] *A Low Cost, Surface Mount X-Band Mixer*, Hewlett-Packard Application Note 1052, 5091-4934E (7/92)
- [2] *Microwave Mixers*, Stephen A. Maas, Artech House, Inc., © 1986

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