## FA 8.2:  A 900MHz / 1.8GHz CMOS Receiver for Dual Band Applications*

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This dual-band CMOS receiver for GSM and DCS1800 applications incorporates hardware sharing between two paths to reduce the number of off-chip components [1]. The receiver is an extension of the Weaver single-sideband architecture [2]. Utilized in References 3 and 4, the Weaver architecture performs two consecutive quadrature downconversion operations on the signal and the image such that if the final outputs are added, the signal is obtained and the image is suppressed and if they are subtracted, the reverse occurs [5]. The fact that the addition or subtraction of the outputs in the Weaver architecture can select or reject two bands symmetrically located around a local oscillator (LO) frequency provides the foundation for the work reported here.

Figure 1 depicts the dual-band receiver architecture. The signal received by the antenna in each band is applied to a duplexer filter to perform band selection. A low-noise amplifier (LNA) and two quadrature mixers boost and translate the signal to an intermediate frequency (IF) of 450MHz. The results of the two bands are combined at IF and undergo a second quadrature downconversion. The RF mixers of the two bands are separate to allow flexibility in choice of device sizes and bias currents, independently optimizing performance of each path.

In the receiver of Figure 1, the first LO frequency is set midway between the GSM and DCS1800 bands, making the two bands images of each other. Band selection is performed by enabling corresponding LNA and RF mixers and adding or subtracting the outputs of the IF mixers. While the Weaver architecture by itself does not provide sufficient image rejection, the 900MHz spacing between the signal and the image allows substantial image filtering in the front-end duplexers. For example, measured insertion characteristics of a 900MHz TDK duplexer (CF6122301A) exhibit 3dB in-band loss and 54dB rejection at 1.8GHz. As a result, the overall image rejection ratio exceeds the GSM and DCS1800 specification (70 dB).

The LNA and RF mixers are shown in Figure 2. Utilizing a cascode stage with inductive degeneration, the LNA draws approximately 5mA of bias current [6]. The mixer is a single-balanced topology with inductive loads tuned to 450MHz, forming the band-pass filter (BPF) in Figure 1. The dc interface between the LNA and the mixer in Figure 2 merits particular attention. To achieve a well-defined bias current in the mixer, the LNA incorporates the dc load $M_3$ with current mirrors $M_4$ and $M_5$. Neglecting the dc drop across $L_2$, note that $V_{GS5} + V_{GS4} = V_{GS3} + V_{GS7}$. Thus, proper ratioing of $M_3$ and $M_7$ with respect to $M_4$ and $M_5$ defines $I_{D7}$ as a multiple of $I_2$. In contrast to capacitive coupling techniques, this approach incurs no signal loss.

With nearly 20dB of voltage gain in the LNA, linearity of the mixers becomes critical. In Figure 2, sufficient linearity is obtained by choosing an overdrive voltage of approximately 600mV for $M_7$ (with a bias current of 2.5mA).

The differential output of the RF mixers, with common-mode level close to $V_{DD}$, is capacitively coupled to the input port of the following mixers. With an overall voltage gain of about 25dB in the LNA and RF mixers, the linearity of the IF mixers tends to limit receiver performance. The input voltage-to-current conver-

sion of the IF mixers incorporates a grounded-source pair, $M_1$ and $M_2$, for higher linearity than in a regular differential pair.

In implementation of the addition or subtraction at the receiver output, the switching is on one of the differential IF signals in the current domain (Figure 3). The multiplexer consisting of $S_1$-$S_4$ negates the signal current according to the logical state of band select. Both IF mixers incorporate the multiplexer to equalize signal delays, but switching is in only one mixer. The size of the switches minimizes the loss in 450MHz signal and in voltage headroom.

A critical issue in the Weaver architecture is the existence of various spurs that result from mixing of multiples of interferer frequencies and the LO frequencies. As illustrated in Figure 4a, if a strong *in-band* interferer at $f_{int}$ leads to a component $kf_{int} \pm mf_{LO1} \pm nf_{LO2}$ that falls in the desired baseband channel, then the signal may be heavily corrupted. The key point is that if $kf_{int}$ is on the same side of $f_{LO1}$ as the desired signal, then it is not suppressed by the image rejection action of the circuit. These mechanisms, caused by the most significant combinations of $k$, $m$, and $n$, are summarized in Figure 4b and quantified below.

The dual-band receiver is fabricated in 0.6μm digital CMOS, occupying a total of 1540x1370μm². All inductors in Figure 2 are integrated with no process modifications. The prototype is characterized at room temperature while running from a 3V supply.

Measured values of the intermodulation products in a two-tone test are plotted in Figure 5a. The $IIP_3$ is equal to -8dBm for the 900MHz path and -6dBm for the 1.8GHz path. Table 1 summarizes measured performance of each receive path. Also shown are the quantities when front-end duplexers with an in-band loss of 3dB and far-out rejection of 54dB are used. We note that the overall noise figure is close to the GSM and DCS1800 specification and parameters such as linearity and image rejection are superior to required values.

Figure 5b plots the conversion gain of a -40dBm interferer after it undergoes the spur mechanisms illustrated in Figure 4b. The interferer experiences a loss of at least $42 + 23 = 65$dB with respect to the desired signal.

An interesting effect that results from choice of the two LO frequencies is in-band leakage to the antenna. That is, if $f_{LO1} = 1350$MHz is mixed with $f_{LO2} = 450$MHz, both 900MHz and 1.8GHz components are generated at the receiver output, potentially leaking to the two inputs. Measurements indicate such components are below -80dBm with low-pass filtering at the output.

*References:*

[1]   Antes, T., C. Conkling, "RF Chip Set Fits Multimode Cellular/PCS Handsets," Microwaves & RF, pp. 177-186, Dec., 1996.
[2]   Weaver, Jr., D., "A Third Method of Generation and Detection of Single-Sideband Signals," Proceedings of the IRE, pp. 1703-1705, June 1956.
[3]   Okanobu, T., D. Yamazaki, "A New Radio Receiver System for Personal Communications," IEEE Transactions on Consumer Electronics, Vol. 41, pp. 795-802, Aug., 1995.
[4]   Rudell, J., et al, "A 1.9GHz Wide-Band IF Double Conversion CMOS Integrated Receiver for Cordless Telephone Applications," ISSCC Digest of Technical Papers, pp. 304-305, Feb., 1997.
[5]   Razavi, B., *RF Microelectronics*, Prentice-Hall, 1998.
[6]   Shaeffer, D., T.H. Lee, "A 1.5V, 1.5GHz CMOS Low Noise Amplifier," 1996 Symposium on VLSI Circuits Digest of Technical Papers, pp. 32-33, June 1996.
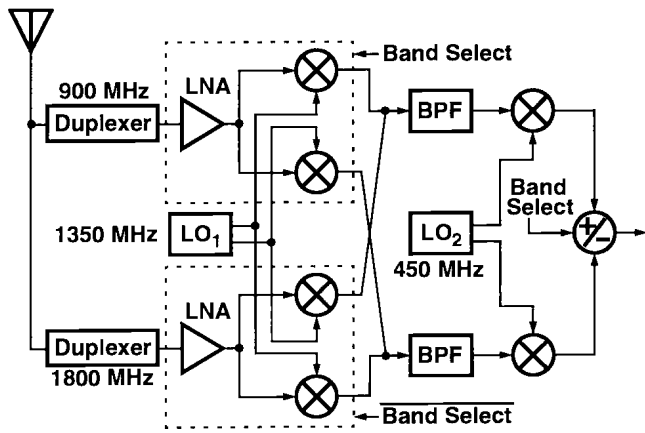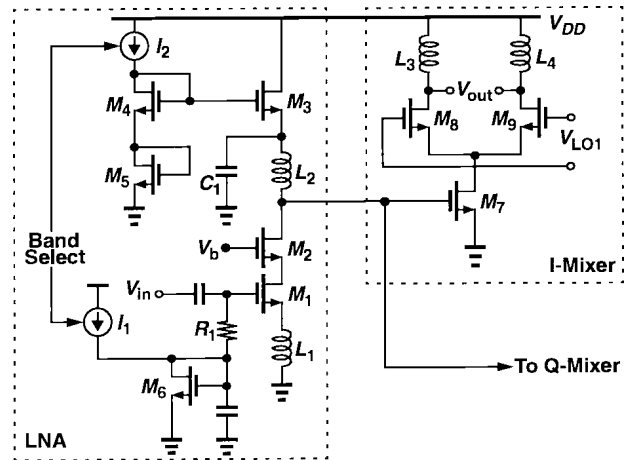
**Figure 1: Dual-band receiver.**



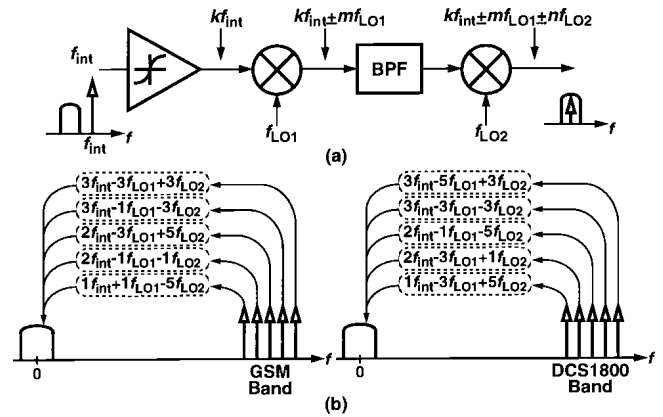**Figure 2: RF stage.**
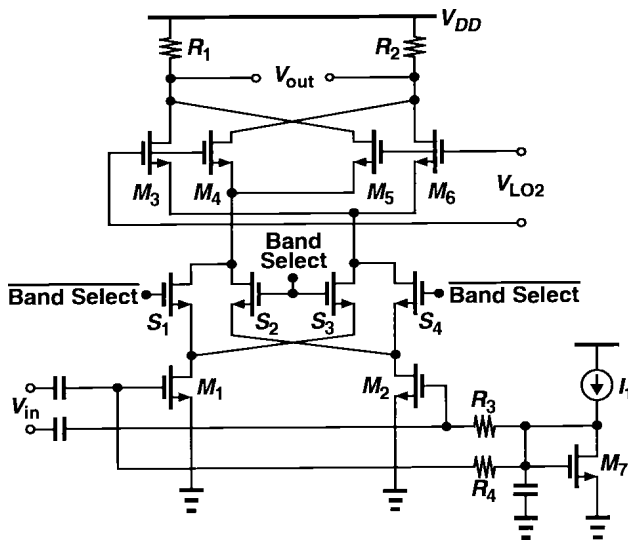


**Figure 3: IF mixer.**



**Figure 4: Spur components down-converted to baseband.**



**Figure 5:** $IIP_3$ **measurement and spur study.**

**Table 1:    Dual-band receiver performance summary.**

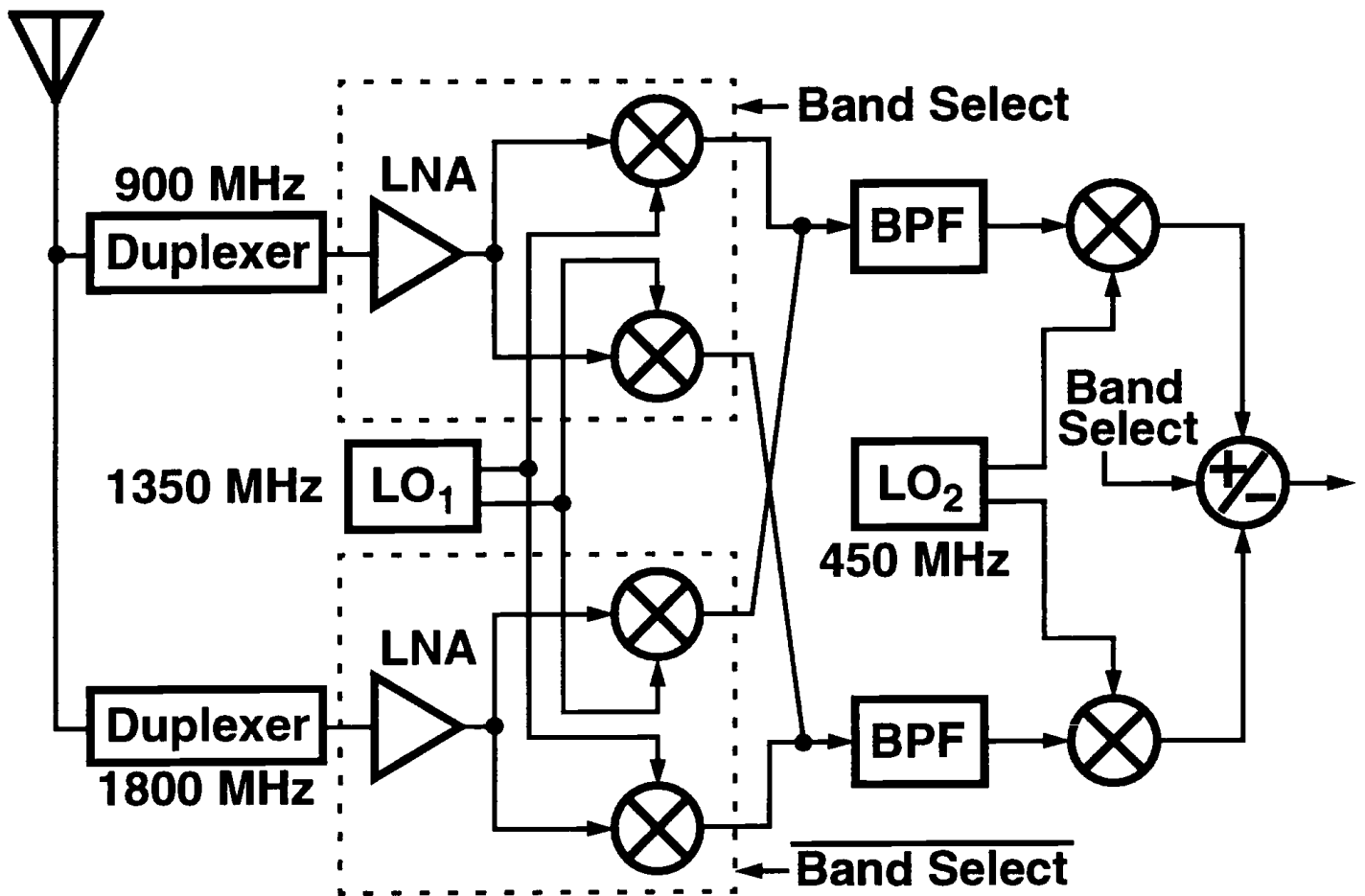|  | GSM | | DCS1800 | | GSM and DCS1800 Spec. |
|---|---|---|---|---|---|
|  | Rx alone | Rx w/ Duplexer | Rx alone | Rx w/ Duplexer |  |
| Noise Figure | 4.7 dB | 7.7 dB | 4.9 dB | 7.9 dB | 7-10 dB* |
| $IIP_3$ | -8 dBm | -5 dBm | -6 dBm | -3 dBm | -18 dBm |
| Image Rejection | 40 dB | 94 dB | 36 dB | 90 dB | 70 dB |
| Input Return Loss | -11 dB | N/A | -12 dB | N/A | N/A |
| Power Dissipation | 72 mW | 72 mW | 75 mW | 75 mW | N/A |
| Voltage Gain | 23 dB | 20 dB | 23 dB | 20 dB | N/A |
| * The exact value depends on the type of the demodulator. | | | | | |

**Figure 1:    Dual-band receiver.**

**Figure 2:    RF stage.**

**Figure 3: IF mixer.**

$kf_{int}$  $kf_{int} \pm mf_{LO1}$  $kf_{int} \pm mf_{LO1} \pm nf_{LO2}$

$f_{int}$

BPF

$f_{LO1}$

$f_{LO2}$

(a)

$(3f_{int}-3f_{LO1}+3f_{LO2})$
$(3f_{int}-1f_{LO1}-3f_{LO2})$
$(2f_{int}-3f_{LO1}+5f_{LO2})$
$(2f_{int}-1f_{LO1}-1f_{LO2})$
$(1f_{int}+1f_{LO1}-5f_{LO2})$

0

GSM
Band

$(3f_{int}-5f_{LO1}+3f_{LO2})$
$(3f_{int}-3f_{LO1}-3f_{LO2})$
$(2f_{int}-1f_{LO1}-5f_{LO2})$
$(2f_{int}-3f_{LO1}+1f_{LO2})$
$(1f_{int}-3f_{LO1}+5f_{LO2})$

0

DCS1800
Band

(b)

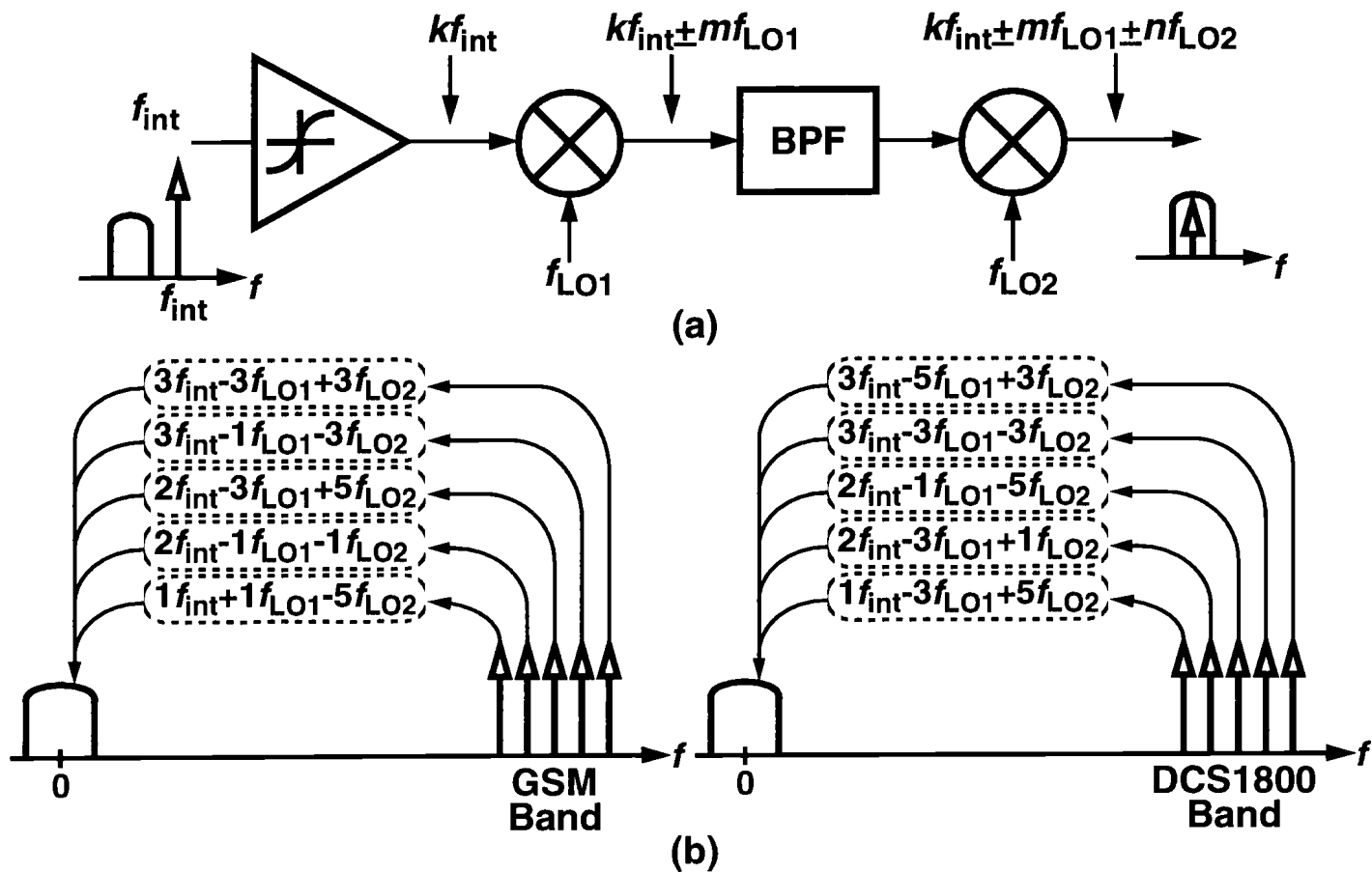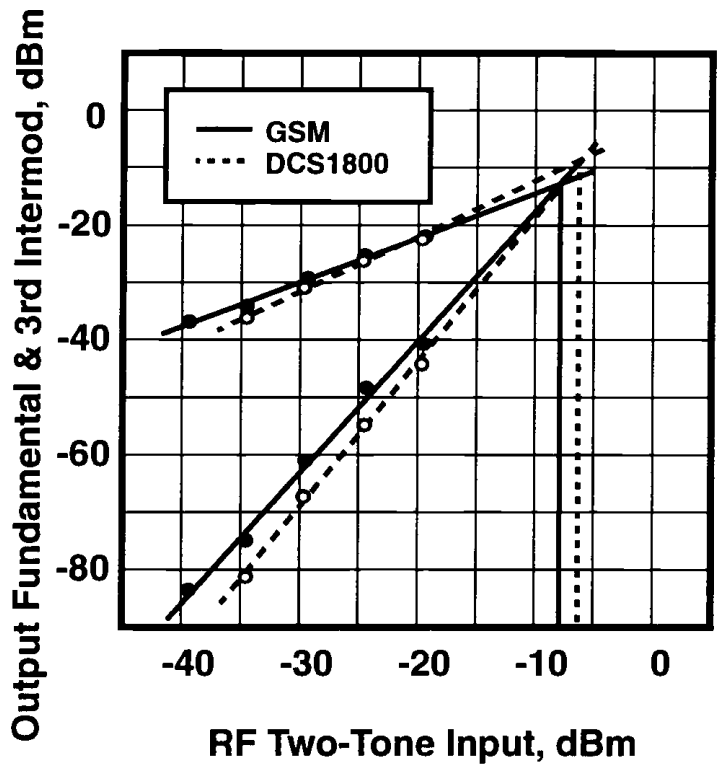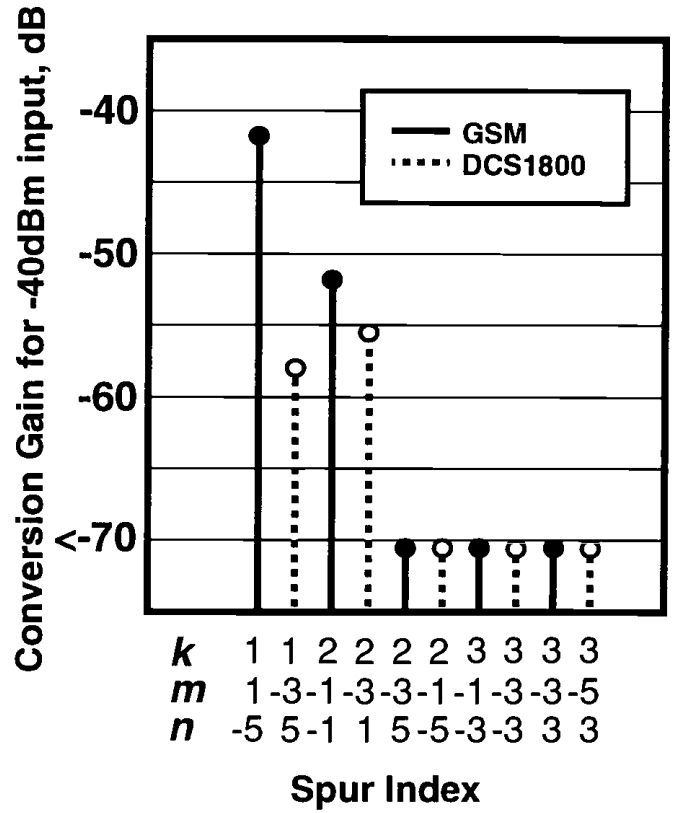**Figure 4:    Spur components down-converted to baseband.**

Figure 5: *IIP₃* measurement and spur study.

|  | GSM | | DCS1800 | | GSM and DCS1800 Spec. |
|---|---|---|---|---|---|
|  | Rx alone | Rx w/ Duplexer | Rx alone | Rx w/ Duplexer | |
| **Noise Figure** | 4.7 dB | 7.7 dB | 4.9 dB | 7.9 dB | 7-10 dB* |
| *IIP$_3$* | -8 dBm | -5 dBm | -6 dBm | -3 dBm | -18 dBm |
| **Image Rejection** | 40 dB | 94 dB | 36 dB | 90 dB | 70 dB |
| **Input Return Loss** | -11 dB | N/A | -12 dB | N/A | N/A |
| **Power Dissipation** | 72 mW | 72 mW | 75 mW | 75 mW | N/A |
| **Voltage Gain** | 23 dB | 20 dB | 23 dB | 20 dB | N/A |
| * The exact value depends on the type of the demodulator. | | | | | |

**Table 1:**      **Dual-band receiver performance summary.**