frequency (IF). Due to phase noise, however, an adjacent undesired signal can be down converted to the same IF frequency due to the phase noise spectrum of the local oscillator. The phase noise that leads to this conversion is located at an offset from the carrier equal to the IF frequency from the undesired signal. This process is called reciprocal mixing. From this diagram, it is easy to see that the maximum allowable phase noise in order to achieve an adjacent channel rejection (or selectivity) of $S \, \text{dB} \, (S \geq 0)$ is given by

$$L(f_m) = C \, (\text{dBm}) - S \, (\text{dB}) - I \, (\text{dBm}) - 10 \log(B), \, \text{ (dBc/Hz)}, \quad (13.50)$$

where $C$ is the desired signal level (in dBm), $I$ is the undesired (interference) signal level (in dBm), and $B$ is the bandwidth of the IF filter (in Hz).

**EXAMPLE 13.5 GSM RECEIVER PHASE NOISE REQUIREMENTS**

The GSM cellular telephone standard requires a minimum of 9 dB rejection of interfering signal levels of $-23$ dBm at 3 MHz from the carrier, $-33$ dBm at 1.6 MHz from the carrier, and $-43$ dBm at 0.6 MHz from the carrier, for a carrier level of $-99$ dBm. Determine the required local oscillator phase noise at these carrier frequency offsets. The channel bandwidth is 200 kHz.

**Solution**

From (13.50) we have

$$L(f_m) = C \, (\text{dBm}) - S \, (\text{dB}) - I \, (\text{dBm}) - 10 \log(B)$$

$$= -99 \, \text{dBm} - 9 \, \text{dB} - I \, (\text{dBm}) - 10 \log(2 \times 10^5).$$

The table below lists the required LO phase noise as computed from the above expression:

<table>
<thead>
<tr>
<th>Frequency Offset $f_m$ (MHz)</th>
<th>Interfering Signal Level (dBm)</th>
<th>$L(f_m)$ (dBc/Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>$-23$</td>
<td>$-138$</td>
</tr>
<tr>
<td>1.6</td>
<td>$-33$</td>
<td>$-128$</td>
</tr>
<tr>
<td>0.6</td>
<td>$-43$</td>
<td>$-118$</td>
</tr>
</tbody>
</table>

This level of phase noise requires a phase-locked synthesizer. Bit errors in GSM systems are usually dominated by the reciprocal mixing effect, while errors due to thermal antenna and receiver noise are generally negligible.

13.4 FREQUENCY MULTIPLIERS

As frequency increases into the millimeter wave range it becomes increasingly difficult to build fundamental frequency oscillators with good power, stability, and noise characteristics. An alternative approach is to produce a harmonic of a lower frequency oscillator through the use of a frequency multiplier. As we saw in Section 10.3, a nonlinear element may generate many harmonics of an input sinusoidal signal, so frequency multiplication is a natural occurrence in circuits containing diodes and transistors. Designing a good-quality frequency multiplier, however, is a difficult task that generally requires nonlinear analysis, matching at multiple frequencies, stability analysis, and thermal considerations. We will discuss some of the general operational principles and properties of diode and transistor frequency multipliers, and refer the reader to the literature for more practical details [5].