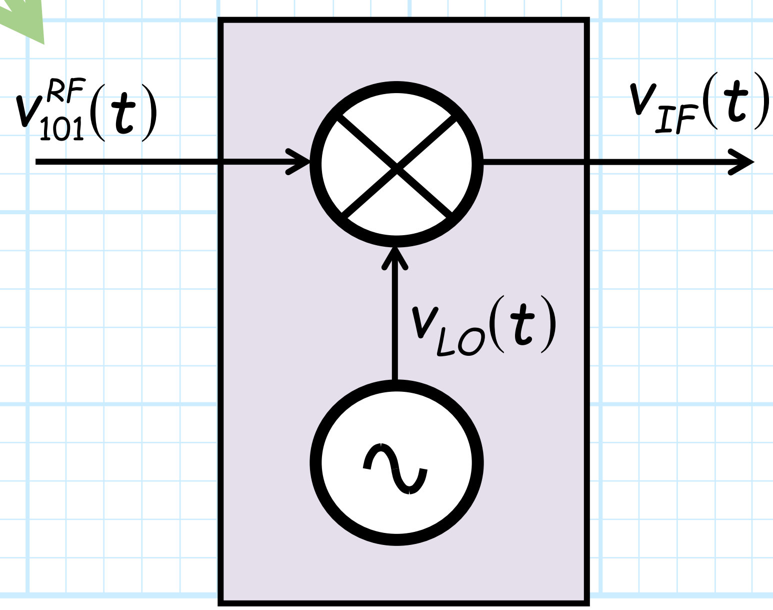
# Phase Noise: Why it matters

Say that the RF signal $v_{RF}(t)$ is the transmitted signal of "**101 the Fox**".

"The Fox" is an **FM** (Frequency Modulated) station, and so some **delightful tune** of Journey, or REO Speedwagon, or **Led Zeppelin**, or is expressed by the **relative phase function**—let's call it $\varphi_{LED}(t)$:

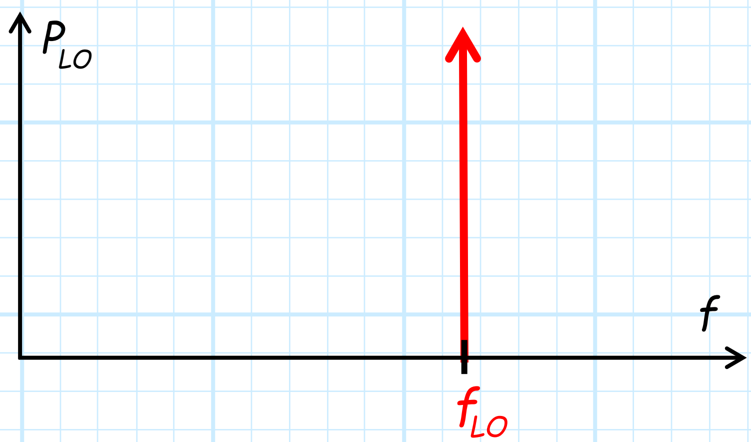
$$v_{101}^{RF}(t) = A_{101} \cos\left[2\pi\left(101.1\times 10^6\right)t + \varphi_{LED}(t)\right]$$

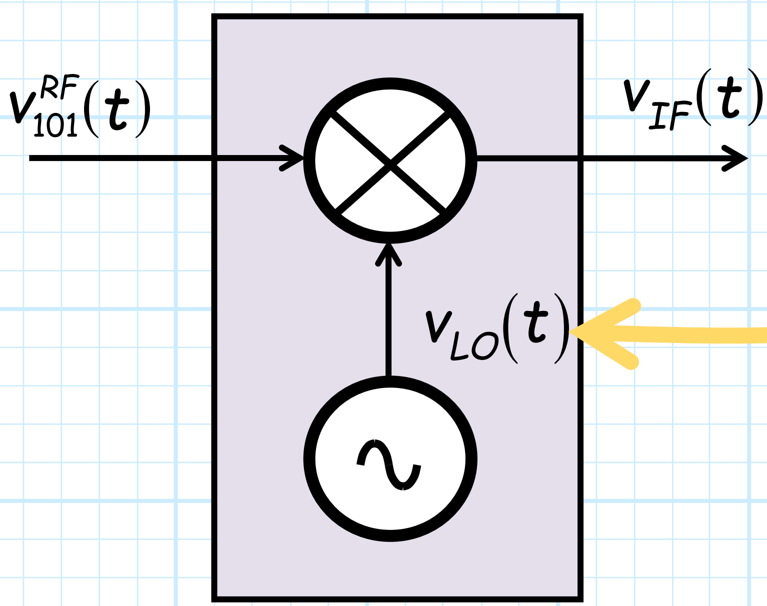



# If the LO is perfect

Now, let's say that we have a **perfect** Local Oscillator—it generates a perfectly **pure tone**:

$$v_{LO}(t) = A_{LO} \cos[\omega_{LO} t]$$

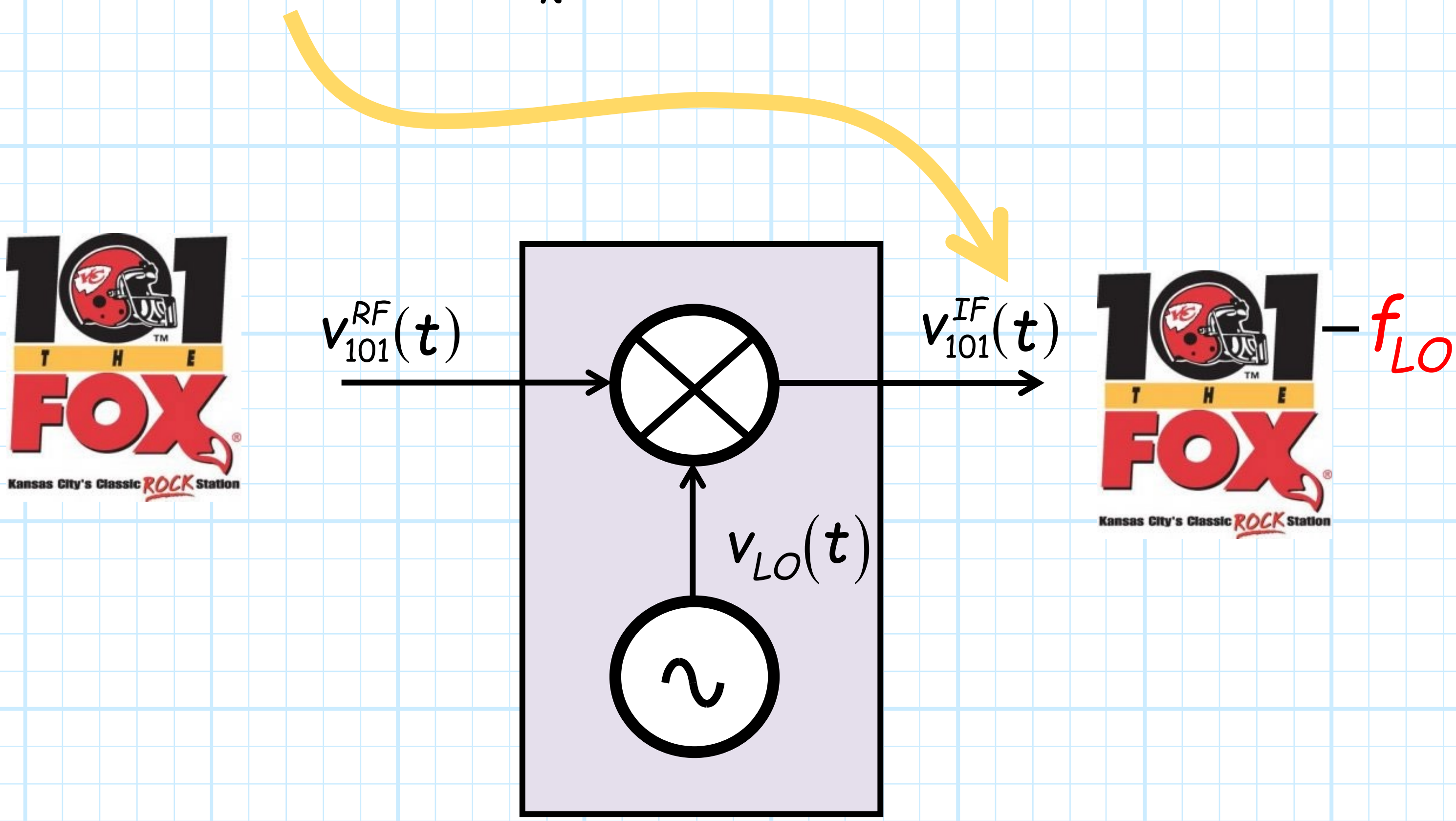


# No longer at 101.1 MHz!

When 101 the Fox is **mixed** with this pure LO tone, there will be this "down-converted" term at the **IF port**:

$$v_{101}^{IF}(t) = A_{101}\frac{2}{\pi}\cos\left[2\pi\left(101.1\times10^{6}-f_{LO}\right)t+\varphi_{LED}(t)\right]$$



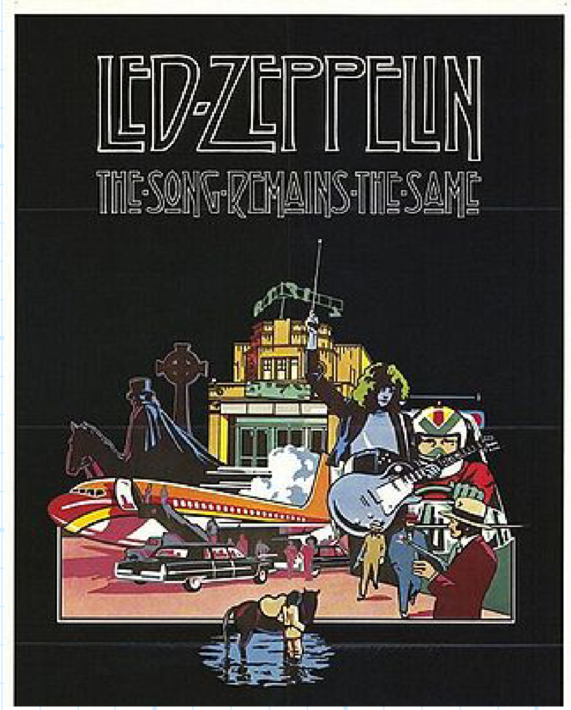
# Different frequency, but same modulation

Again, we see that **this IF signal**:

$$v_{101}^{IF}(t) = A_{101}\frac{2}{\pi}\cos\left[2\pi\left(101.1\times 10^6 - f_{LO}\right)t + \varphi_{LED}(t)\right]$$

is essentially the **same** as our original **RF signal** (101 the Fox!):

$$v_{101}^{RF}(t) = A_{101}\cos\left[2\pi\left(101.1\times 10^6\right)t + \varphi_{LED}(t)\right]$$

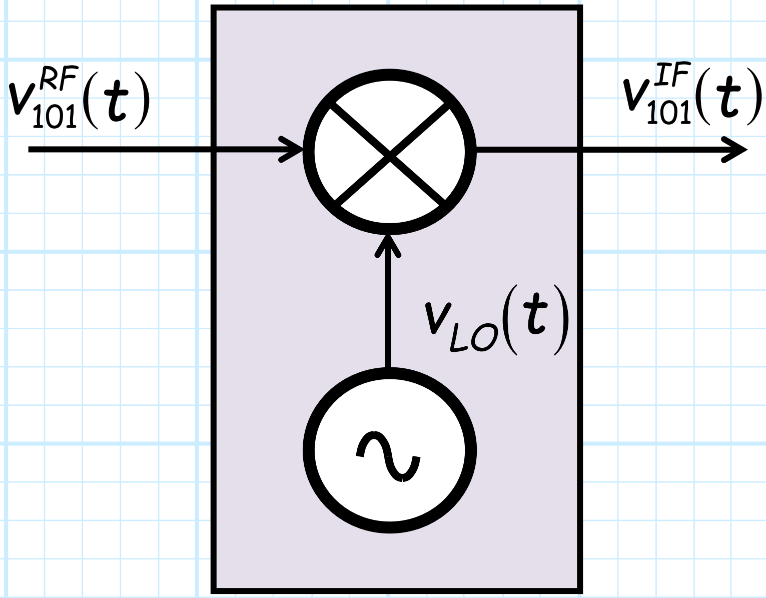


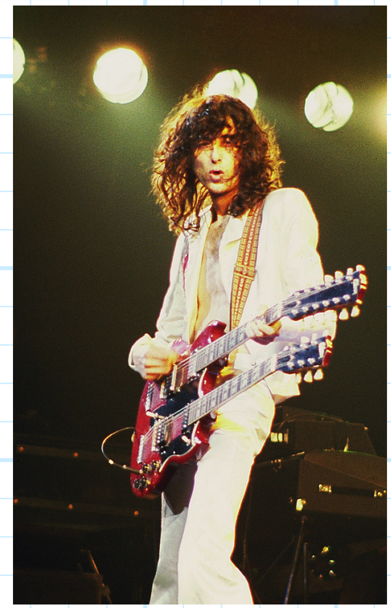

The frequency has been shifted **downward** to some smaller value $f_{IF} = 101.1\times 10^6 - f_{LO}$.

But otherwise, "the **song remains the same**"!

# Down-conversion did not alter the music

In other words, the **classic** guitar riffs of **Jimmy Page** remain **unaltered** (i.e., the **relative phase** $\varphi_{LED}(t)$ is unperturbed!) by this down-conversion **!!!!!!!**



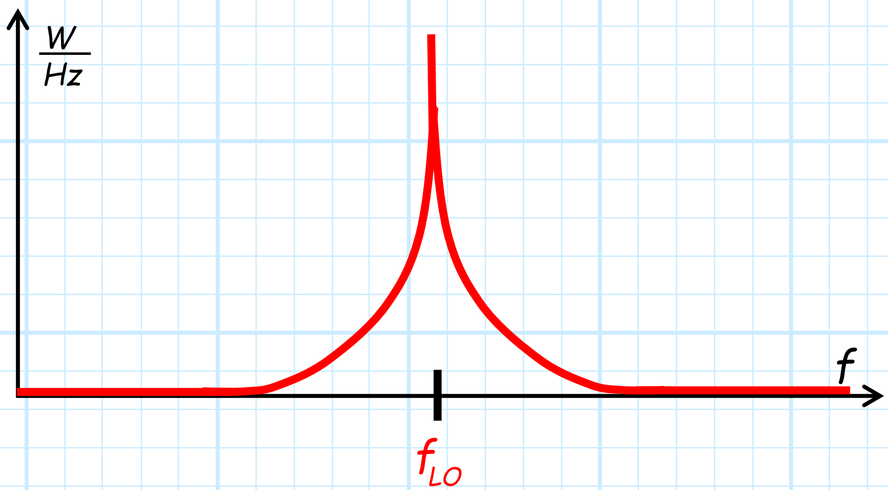



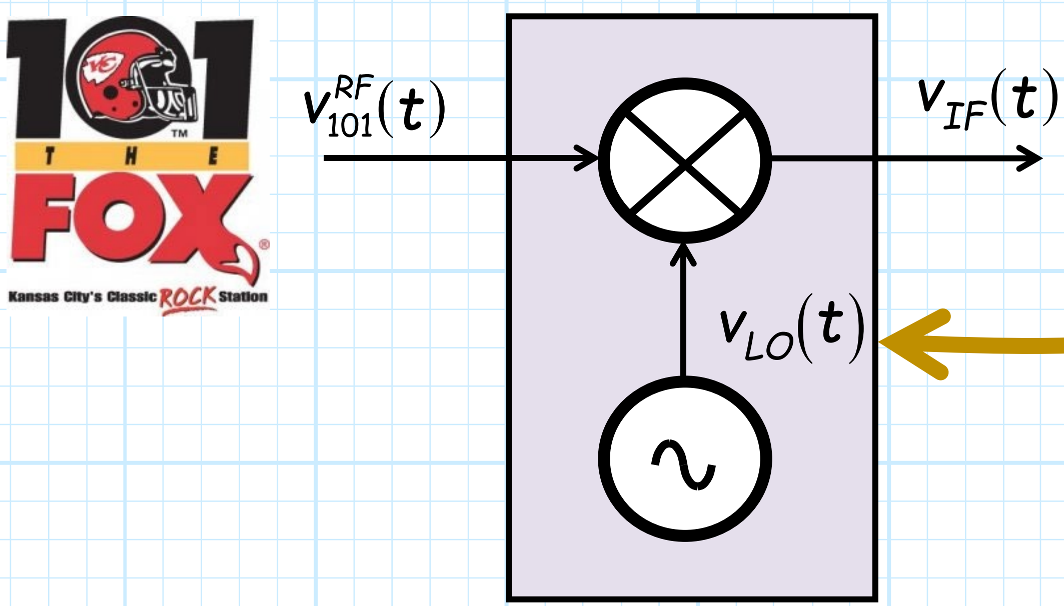
Thus, a frequency **demodulator** will be able to extract from the **relative** phase $\varphi_{LED}(t)$ a **near perfect** rendition of Jimmy's **immense talent**.

# Alas, oscillators are NOT perfect

Now, consider the **same** process, **but** let's (justifiably) assume the Local Oscillator is **contaminated by phase noise** $\varphi_n(t)$:

$$v_{LO}(t) = A_{LO}\cos\left[\omega_{LO}t + \varphi_n(t)\right]$$



# Is it Jimmy—or is it phase noise?

The down-conversion term now has a **different form**:

$$v_{101}^{IF}(t) = A_{101}\frac{2}{\pi}\cos\left[2\pi\left(101.1\times10^{6}-f_{LO}\right)t+\left(\varphi_{LED}(t)-\varphi_{n}(t)\right)\right]$$

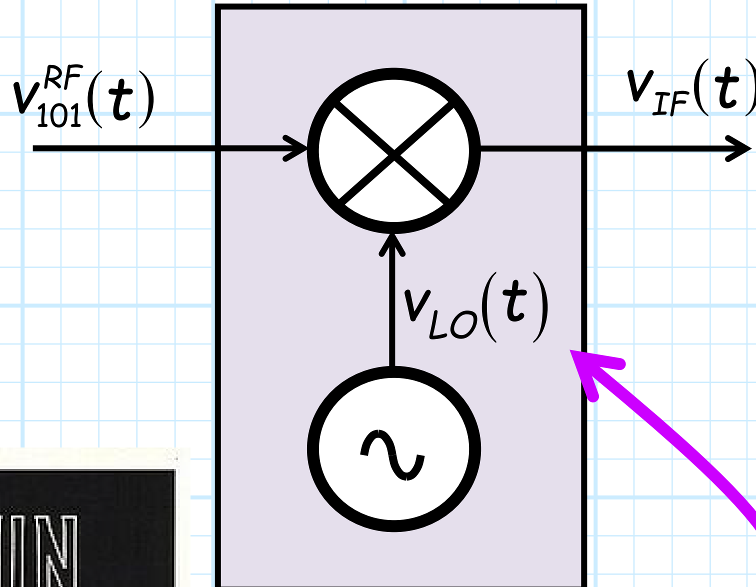
Hopefully, **you** see the **problem**!

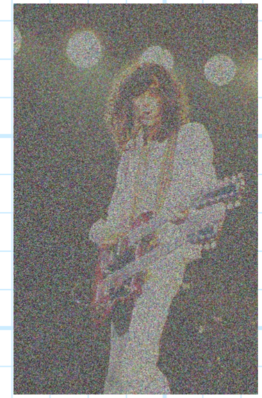
The **relative phase** includes **both $\varphi_{LED}(t)$ and $\varphi_n(t)$**.

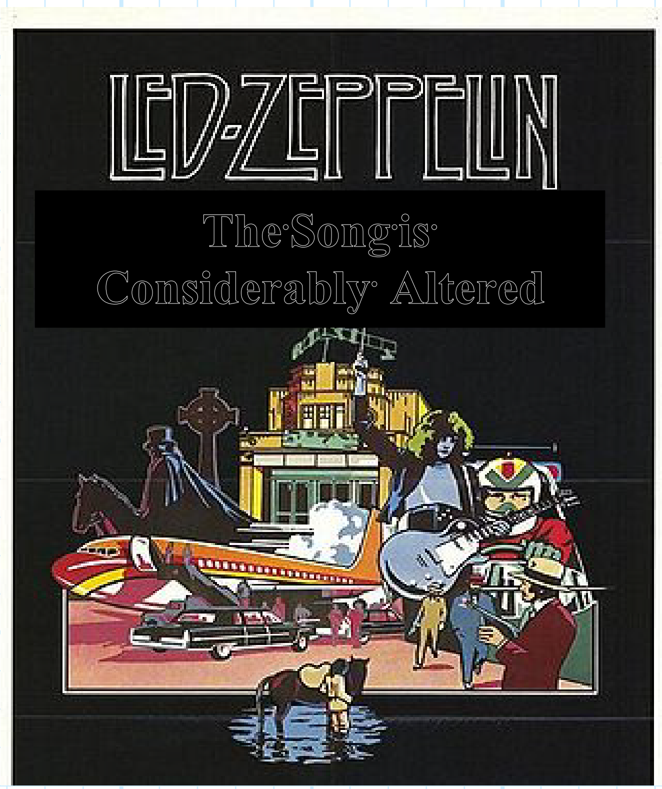
A **frequency** demodulator **cannot** distinguish between the two signals $\varphi_{LED}(t)$ **and** $\varphi_n(t)$—it will recover the **sum** of these two functions!

As a result, the FM demodulated signal will have a **random noise** component, due directly to the **phase noise** of the Local Oscillator.

# The song is considerably altered






$$v_{LO}(t) = A_{LO} \cos\left[\omega_{LO} t + \varphi_n(t)\right]$$

→ If your LO has **significant phase noise**, the song **will *not* remain the same**!

# Turning up the power doesn't help!

**Q:** *Yikes! How do we get rid of the **deleterious effect of phase noise**?*

*Does "101 the Fox" need to just **increase** its transmitter power?*

**A: Look** at the **math**.

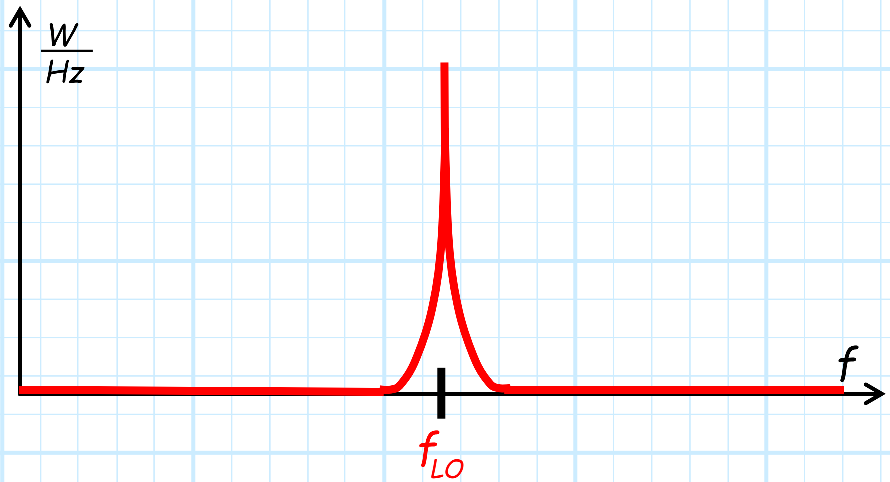
$$v_{101}^{IF}(t) = A_{101}\frac{2}{\pi}\cos\left[2\pi\left(101.1\times 10^6 - f_{LO}\right)t + \left(\varphi_{LED}(t) + \varphi_n(t)\right)\right]$$

We **cannot** reduce the effect of **phase noise** by **increasing** the **RF signal power** (i.e., by increasing $A_{101}$).

→ *"We cannot **stop** phase noise, we can only hope to **contain** it !"*

# Carefully select/design/specify your oscillator

Thus, we must **design/select/use** Local Oscillators with **very low phase noise** (e.g. $|\varphi_n(t)| \lll 1.0$).




**If** the phase noise is **small enough**:

$$v_{LO}(t) = A_{LO}\cos[\omega_{LO}t + \varphi_n(t)] \cong A_{LO}\cos[\omega_{LO}t]$$

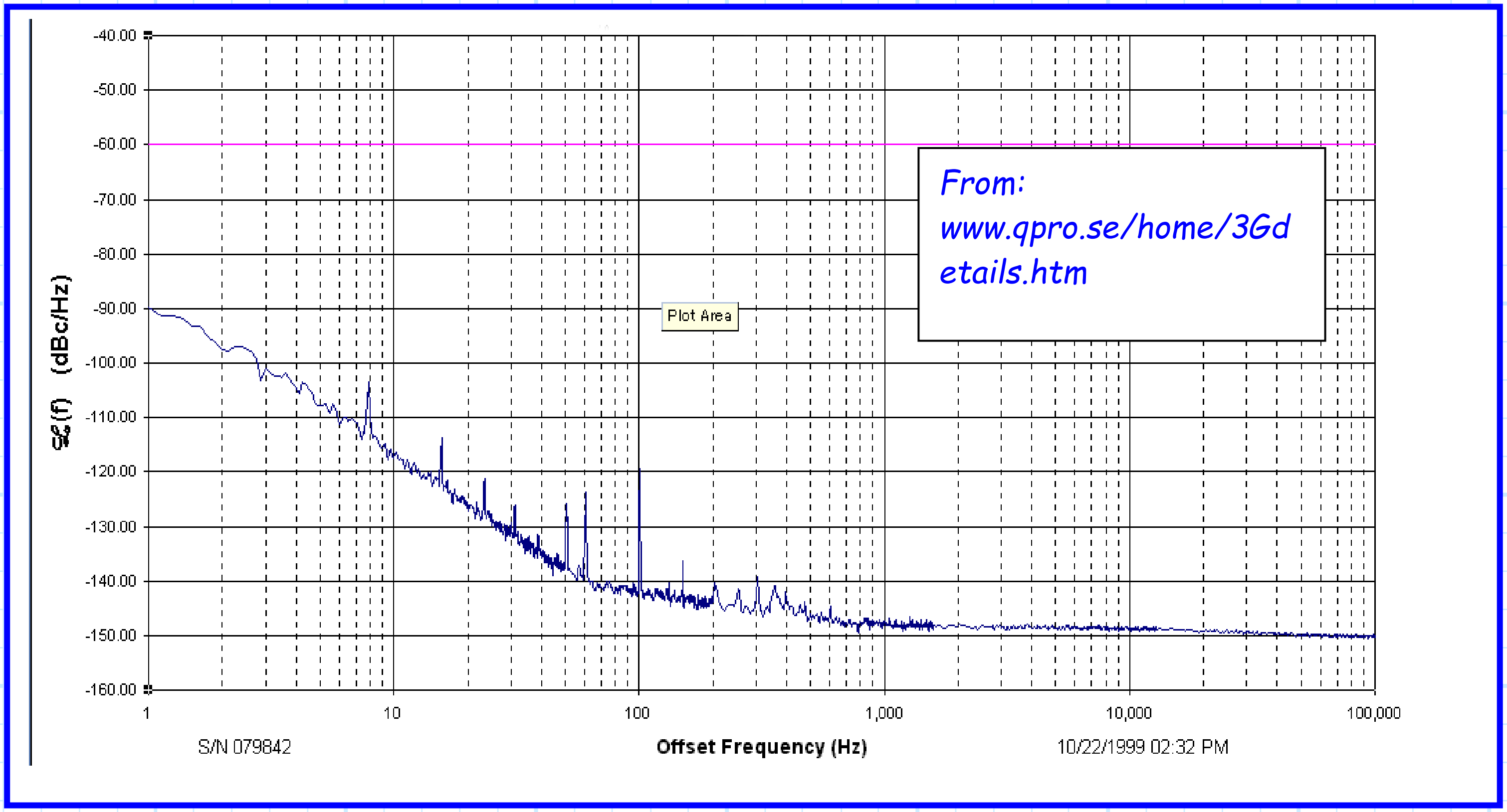
then its effect will be **nearly unperceivable** at the output of the frequency demodulator.

**Q:** *So how **low** should this phase noise be? How small is **small enough**?*

**A:** Of course, the answer to this is very **subjective** (what defines "**nearly unperceivable**"?), and depends on **many** different factors.

# Low phase-noise oscillators are plentiful

However, we find that low-noise LO can **easily** have phase noise of **less** than **-100** ***dBc*** in a **1** ***Hz*** **bandwidth**, at frequencies as close as **100 Hz** from the **carrier** frequency!




But, phase noise typically **increases** as the **carrier frequency** increases—it is **much** easier to build a low phase-noise oscillator at $f_0 = 100MHz$ than one at a carrier frequency of $f_0 = 10GHz$ .