Some observations on phase noise from local oscillator strings.

By
KØCQ
Dr. Gerald N. Johnson, retired P.E.

Color code

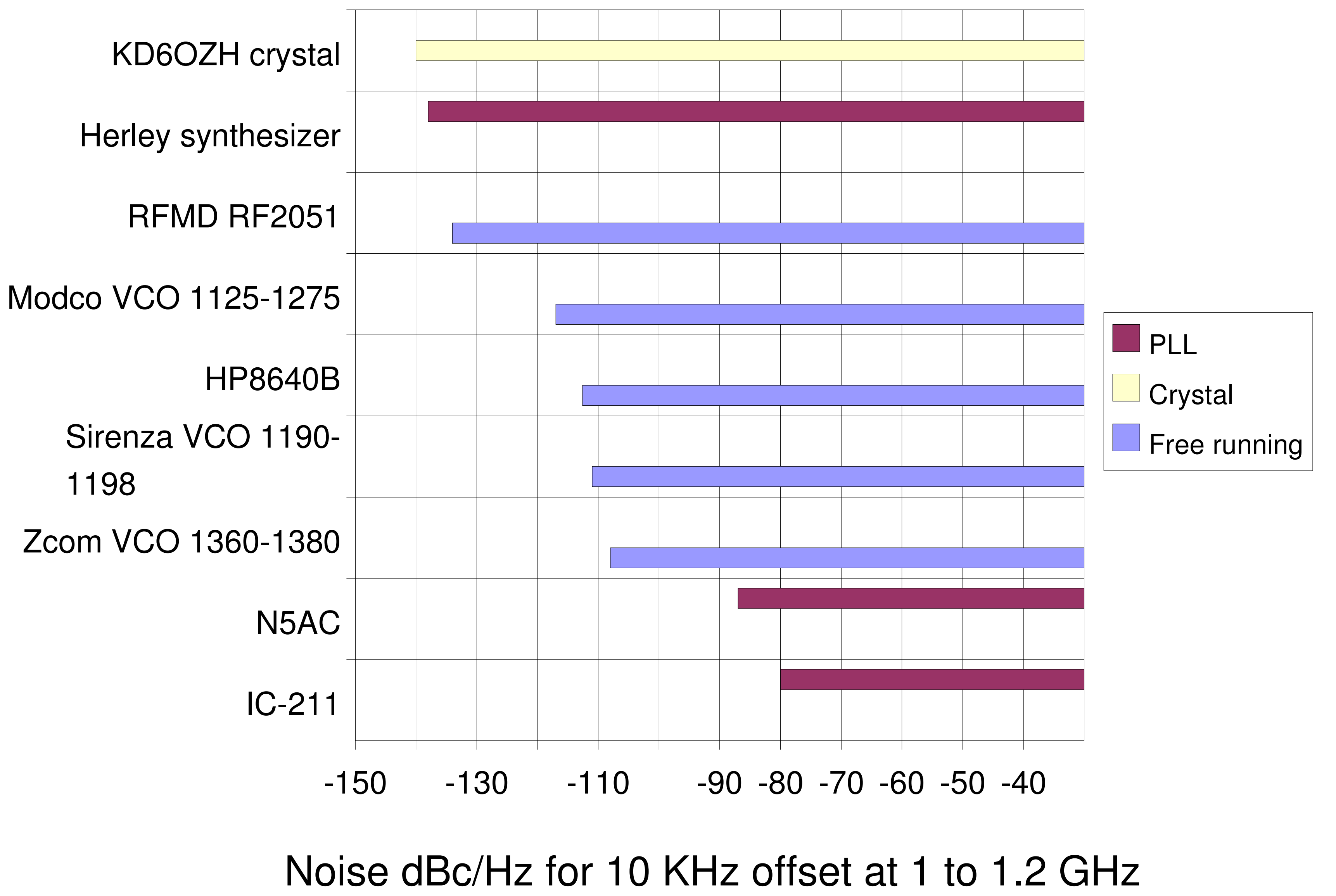
Slides with this white background were the original presentation.

Background color for slides containing what I said or should have said.

Background for MUD participants' comments.

Background for 2009 project plans.

Some oscillator phase noise levels



This is what (I think) I said

This chart shows a few oscillators and their phase noise levels at 10 kHz offset and multiplied or divided to about 1 GHz.

The brown ones are synthesizers, the yellow ones are crystals, and the blue ones are free running oscillators, neither phase locked nor controlled.

The KD6OZH oscillator has great care taken to make it low noise even though it is locked to a 10 MHz reference.

The Herley source is a 10 GHz range dielectric resonator oscillator disciplined by a 100 MHz crystal, in turn disciplined by a 10 MHz standard.

This is what (I think) I said

The Modco, Sirenza, and Zcom oscillators are narrow frequency range and relatively low noise voltage controlled oscillators in the 1 to 1.2 GHz range.

The N5AC oscillator you just heard about, and the IC-211 has been the worlds standard for the poorest ever commercial 2m radio for phase noise.

The RFMD is the on board oscillator in a fractional-N synthesizer chip.

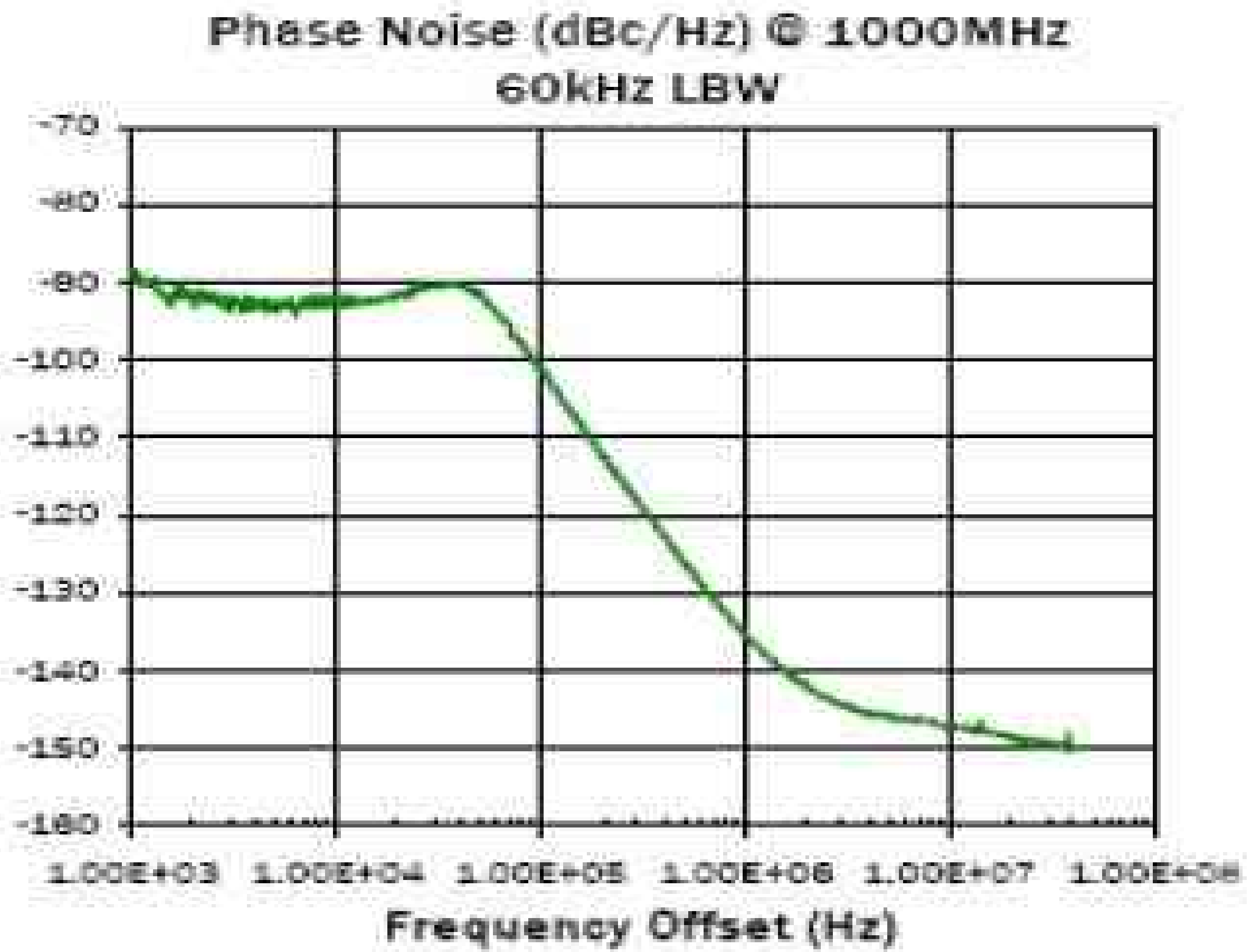
Say what?

What was the real offset for that RFMD chip? -140 dBc/Hz is good for a crystal oscillator. Really superb for a free running oscillator!

And I said:

Excuse me? What was that really? That's too good for a synthesizer or VCO.

From the RFMD 2501 data sheet.



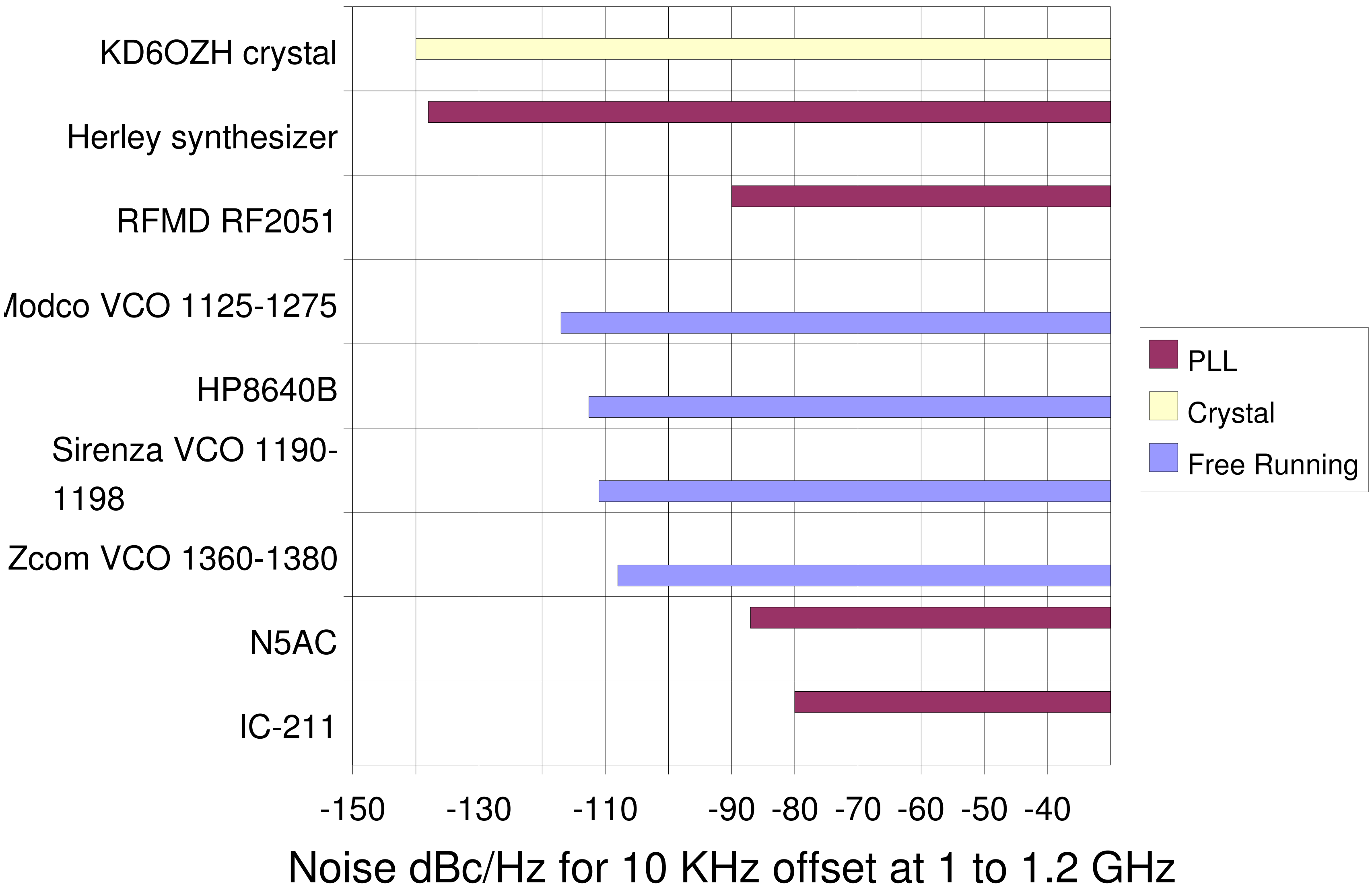
And I said:

Ahah. Specmanship. That's not the noise at 10 kHz that I had assumed, that's the noise at 1.8 MegaHz! Clearly by the shape of the phase noise spectrum its locked, not free running. This note “60 kHz LBW” means 60 kHz loop bandwidth as it shows by being flat out to about 60 kHz.

So we revise the chart.

That's not so great. And it took a wide control loop bandwidth to achieve -90 dBc/Hz at 1 GHz.

Revised oscillator phase noise levels

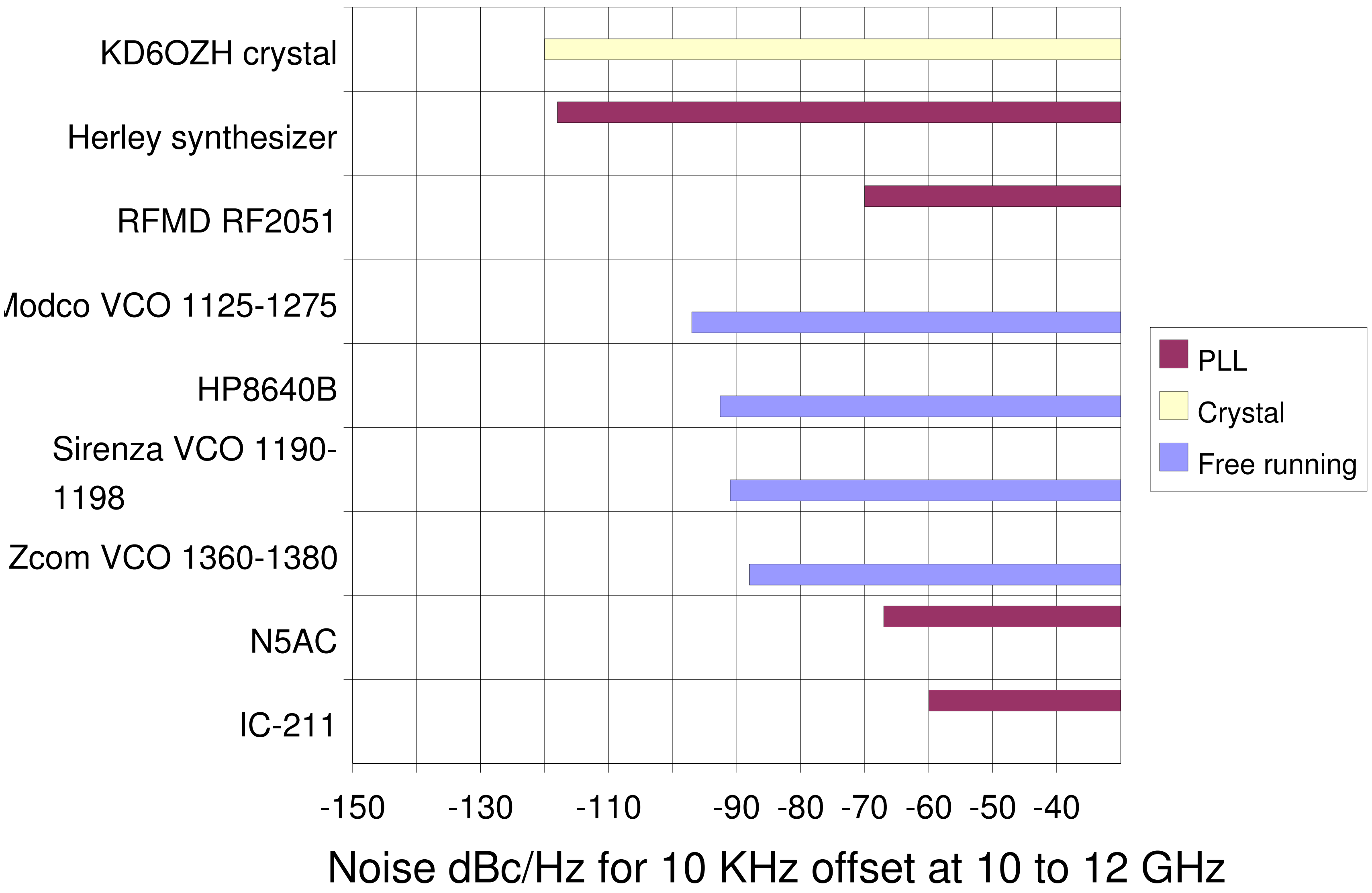


And I said:

So for for the 10 GHz range these phase noises go up by a factor of 20 * $\log_{10}$ N dB where N is the multiplication (or division) factor. Multiplying by 10 increases the phase noise by 20 dB with a PERFECT multiplier. Real world multipliers add some more phase noise.

Besides phase noise, all oscillators have amplitude noise which we neglect because BALANCED mixers ignore it. Single diode, FET, and half frequency mixers do not ignore amplitude noise. And any frequency multiplier that has a threshold WILL convert amplitude noise to phase noise.

At 10 to 12 GHz



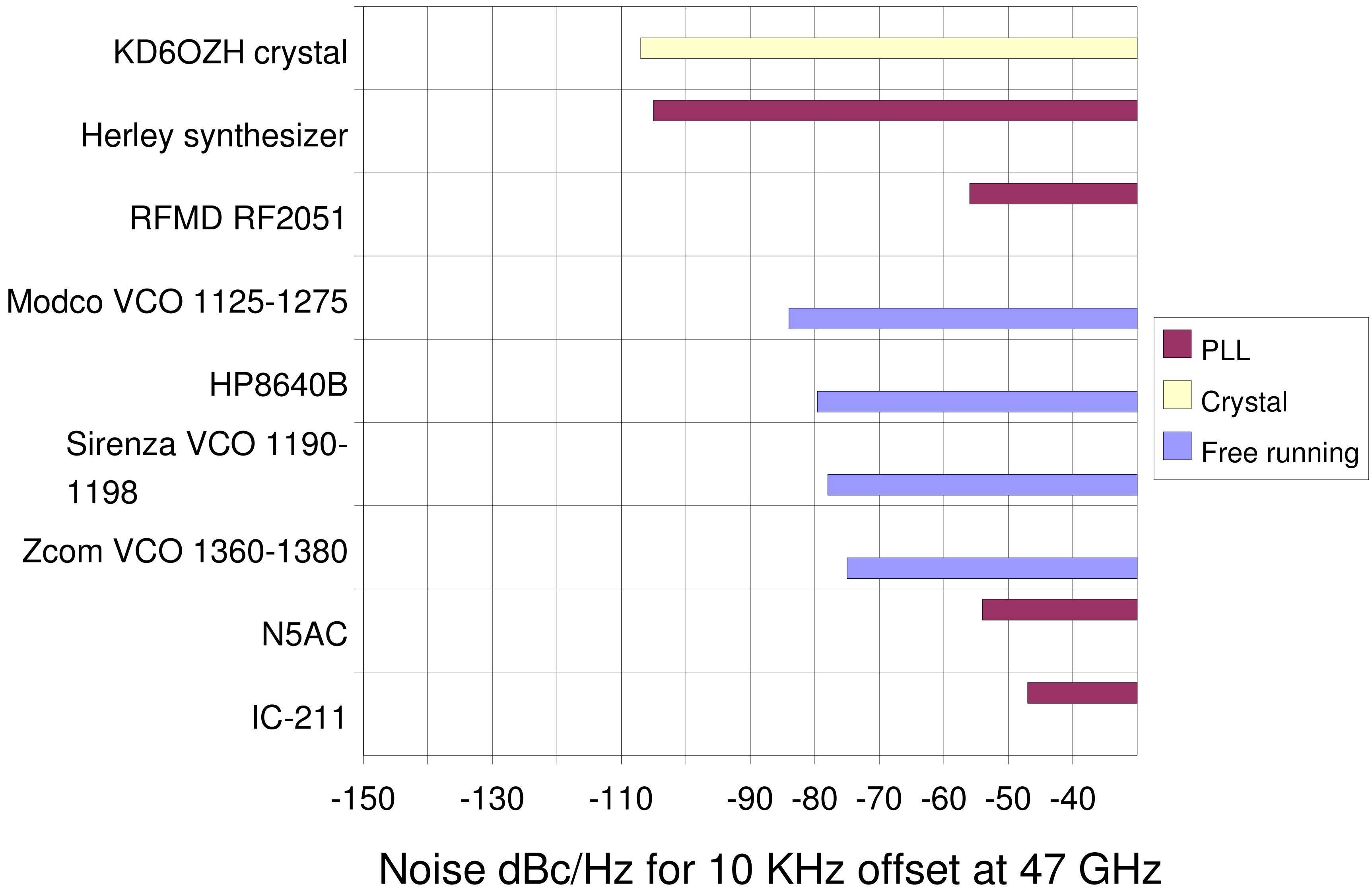
And I said:

Frequency dividers generally improve phase noise by that same factor, except they can add some of their own so the improvement is not as much as the $20 * \log_{10} 1/N$ dB formula would indicate.

I might have said: “Ten-Tec's Omni V and VI used this to synthesize a 5 to 5.5 MHz LO that was clean, by running the synthesizer at 400 MHz and dividing down to 5 MHz. That way they achieved stability and low phase noise at the same time improving on their permeability oscillator that had only had good phase noise and fair stability.”

Then for kicks here's the same phase noises multiplied by another factor of 5 for 47 GHz.

At 47 GHz.


KD6OZH crystal
Herley synthesizer
RFMD RF2051
Modco VCO 1125-1275
HP8640B
Sirenza VCO 1190-1198
Zcom VCO 1360-1380
N5AC
IC-211
PLL
Crystal
Free running
-150
-130
-110
-90
-80
-70
-60
-50
-40
Noise dBc/Hz for 10 KHz offset at 47 GHz

And I said:

This is a very recent Herley advertisement. I have not confirmed their phase noise claims. But at least they do give offsets.

And some recent VCO advertisements.

VCO

These economical VCOs offer very low phase noise in the industry standard ½" square package. Model MD110MST, featuring a frequency range of 1175 to 1275 MHz, is rated -118 dBc @ 10 kHz offset. Custom designs can be supplied with no NRE. ➤ 51

MODCO

GET MORE PRODUCT INFO

L-Band VCO

Model CLV1370A-LF operates from 1360 to 1380 MHz (L-band) with a tuning voltage range of 0.5 to 4.5 Vdc. This VCO features a typical phase noise of -108 dBc @ 10 KHz offset and a typical tuning sensitivity of 24 MHz/V. Size is 0.50 x 0.50 x 0.22". ➤ 60

Z-COMMUNICATIONS

205x SERIES SPECIFICATIONS

	Units	RF2051	RF2052	RF205
Fractional-N PLL		Yes	Yes	Yes
On-chip VCOs		Yes	Yes	No
RF Mixers		2	1	1
DC Parameters				
Supply voltage	V	3.0	3.0	3.0
Supply current (low current setting)	mA	55	55	55
VCO and Synthesizer				
Input Reference Frequency	MHz		10 to 104	
LO frequency	MHz	300 to 2400	300 to 2400	-
Open loop VCO phase noise at 500 MHz LO frequency	dBc/Hz	-140	-140	-
RF Mixer				
RF and IF port frequency range	MHz		50 to 2500	
Noise figure (low current setting)	dB	-	9.5	-
Input IP3 (high linearity setting)	dBm	-	20	-

FEATURES

- 2.7 V to 3.6 V operation
- Fractional-N synthesizer—1.5 MHz resolution
- Integrated LO buffers, high-linearity RF mixers and low phase noise VCOs
- Programmable linearity mixers for power saving
- Two frequency registers for FSK modulation
- Three-wire serial control interface

WWW.MPDIGEST.COM ➤ 255

For sales or technical support, contact RFMD at 336.678.5570, Ext. 1 or sales-support@rfmd.com
For customer service, contact RFMD at 336.678.5570, Ext. 2 or customerservice@rfmd.com

7628 Thorndike Road, Greensboro, North Carolina 27409-9421 USA • Phone 336.664.1233 • Fax 336.931.7454

RFMD

rfmd.com/RF205

And I said:

And this is the advertisement from RMD where I got that -140 dBc/Hz figure. And it says “open loop VCO phase noise at 500 MHz.” But on the data sheet they show only closed loop. The 1 GHz oscillator is a bit noisier than the 500 MHz oscillator. I have edited this a bit to squeeze it on one slide. Only by sliding a spread out table together. So for the next slide I show that close up.

205x SERIES SPECIFICATIONS

	Units	RF2051	RF2052
ractional-N PLL		Yes	Yes
n-chip VCOs		Yes	Yes
F Mixers		2	1
DC Parameters			
upply voltage	V	3.0	3.0
upply current (low current setting)	mA	55	55
VCO and Synthesizer			
nput Reference Frequency	MHz		10 to 104
O frequency	MHz	300 to 2400	300 to 2400
pen loop VCO phase noise at 500 MHz LO frequency	dBc/Hz	-140	-140
RF Mixer			
F and IF port frequency range	MHz		50 to 2500
loise figure (low current setting)	dB	-	9.5
nput IP3 (high linearity setting)	dBm	-	20

What are the effects?

LO phase noise can increase the receiver noise floor by mixing in RF noise using the entire LO noise spectrum and RF spectrum. Consider that for each if bandwidth of LO noise at some offset, there is RF noise to be mixed to the IF frequency. While many talk about this, none show numbers and the rough numbers I calculate show its not a problem unless the phase noise is obnoxiously strong and the system noise temperature is extremely low.

And here's where I began to wave my arms and stumble.

Many articles and books talk about raising the noise floor from LO phase noise and NOT ONE puts numbers on it. How much phase noise is too much? Is it affected by IF bandwidth? Surely by RF bandwidth and phase noise bandwidth. It is less than reciprocal mixing of discrete nearby strong signals.

Failing to find or compute numbers I think:

Continuing to flounder:

That since there is RF noise for every bit of LO noise, even out a few MHz where even the poor sources are down 140+ dB, the LO * RF spectrum splits into IF bandwidth segments and these stack up or fold over at the IF. So that within the RF and LO bandwidth the mixed signals for each IF bandwidth of RF get added in the IF. Which means:

Firmly inserting hoof into mouth:

That the narrowest IF is most sensitive to RF noise mixed with phase noise, while the wide IF of the NF meter is virtually immune to it.

But even so the total noise power is small unless the LO phase noise is large, so that with a 100 Hz IF bandwidth, I get figures like -60 dBc/Hz phase noise over a few MHz bandwidth just beginning to affect the system NF or MDS.

Continuing without extracting foot:

Say the LO phase noise is -60 dBc/Hz over a MHz, constant. A worst case. And over that MHz the RF noise is constant, not an unusual situation. Then in one IF bandwidth at RF, the RF noise to the IF is 60 dB below the RF noise to the IF from the LO signal. If the IF bandwidth is 100 Hz, that's 40 dB less than 1 MHz or there are 10,000 IF bandwidths in 1 MHz.

The coup de grâce

10,000 IF bandwidths all folded together of noise 60 dB down is still 20 dB down from the noise from the clean LO and the RF noise.

But take the RF and LO noise bandwidth out to 100 MHz and the noise power at the 100 Hz IF has just doubled. But a -60 dBc/Hz phase noise bandwidth of 100 MHz isn't common except for a poorly filtered noise source like a Gunn diode or klystron.

And from the audience:

WA1ZMS/4 says his employer figures -90 dBc/Hz is good enough for their equipment.

What are the effects?

The main effect in the real world comes from reciprocal mixing where that LO phase noise mixes with RF signals outside the IF passband to make noise at the signal frequency. The stronger the phase noise, the more numerous the unwanted signals, and the stronger the unwanted signals, the stronger this effect.

What are the effects?

You say your rover hill top is quiet? Are you sure? What about all those part 15 noises on 902, 2.4 and 5.6 Ghz? What about those WiFi servers using those bands partly for users and partly for point to point links?

And at MUD 2004, KK7B reminded us that our transverters may supply all the spurs we need to have such reciprocal mixing, especially in the IF radio.

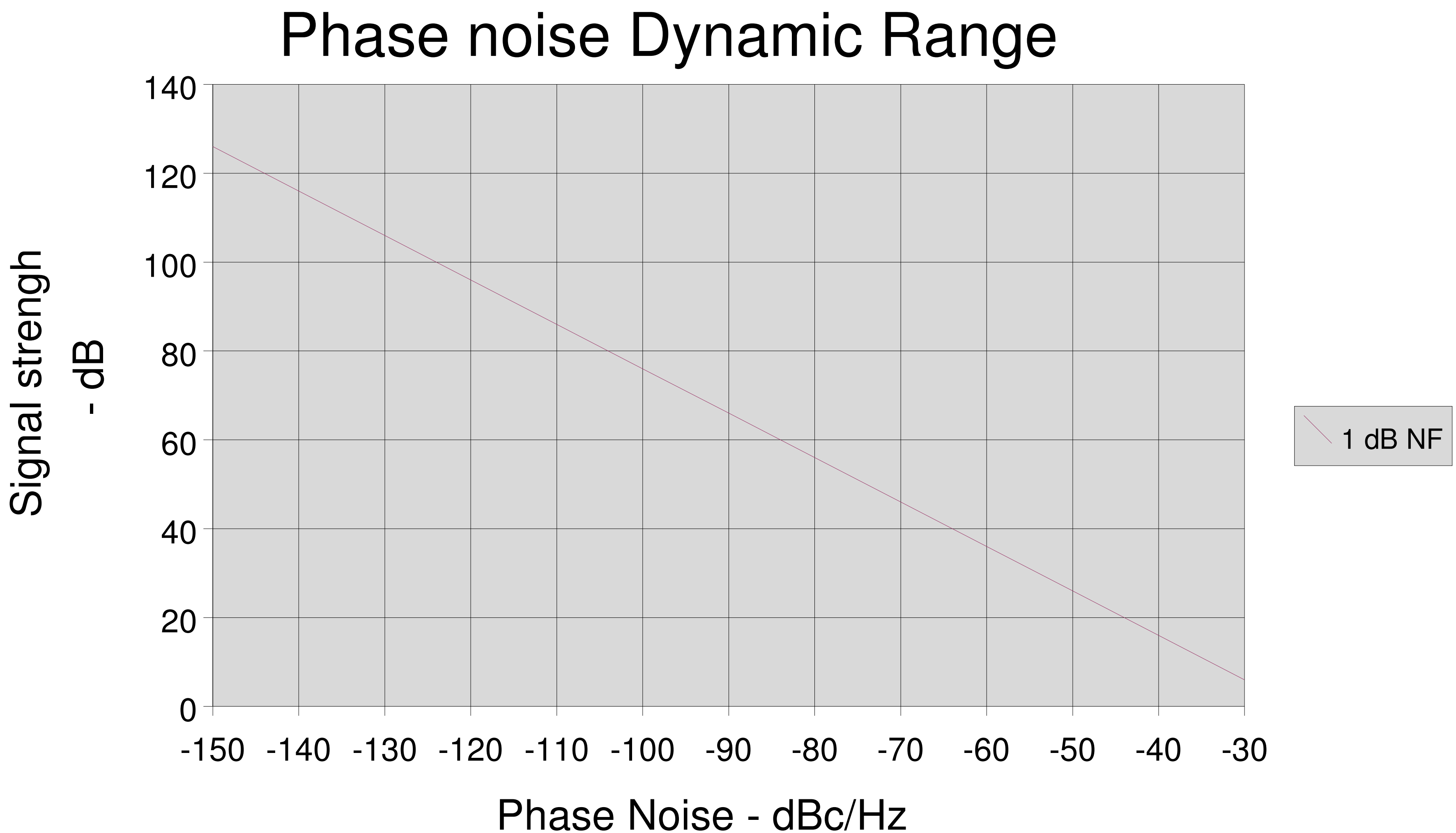
Here is a graph of the effect on system NF for any level of phase noise, whether the system's LO or the interfering signal's phase noise, for a 2 KHz bandwidth. The effect is greater for a better NF front end, not as much for the poorer NF. Generally the curves for other NF plot parallel to this line offset by the difference in NF.

This is for the phase noise at the signal spacing. Multiple signals add up in noise power at the IF.

Reciprocal Mixing

Signal strength to raise the receiver noise floor 3 dB in 2 KHz IF

bandwidth..



Questions?

Questions?

Here there were questions that I have forgotten. There was considerable discussion, but my trigger question to go on, “What to do?” wasn't asked so I didn't go on with the rest of the slides.

What to do?

What to do?

1. Consider not using the N5AC synthesizer as a LO, its noisy for signal populated environments. It makes receivers more sensitive to reciprocal mixing and it makes transmitters broad. Use crystals instead.

What to do?

2. Consider adding to its the N5AC frequency agility but use it only as a marker. Ham gear from 1920 until digital radios worked with crystal markers or frequency meters. Microwave gear still can. Say, set up the PIC chip to allow for outputs on 902, 903, 1152, 1200, and 1296. With the many harmonics of 1152 that set of frequencies gives markers from 902 to 24,192, possibly higher.

What to do?

3. Use a better VCO. On-chip VCOs historically have been poor, often cross coupled RC free running flipflops accompanied by much digital noise and with a wide tuning range making the tuning sensitivity a MHz per 10 millivolts. That sensitivity demands the tuning line noise be nanovolts and that level of quiet is not possible in a chip. Thermal noise is more than that.

What to do?

3. (cont) Consider VCOs by Modco or Serenza, with narrow band tuning they claim phase noise levels 25 dB better than the N5AC result.

These choices do have very narrow tuning ranges so different transverters may need different VCOs, which shifts concerns back to the custom crystal problem and that custom crystal may be cheaper than the custom low noise VCO.

What to do?

4. Consider a different PLL package. RFMD claims -140 dBc/Hz phase noise from their free running VCO at 500 MHz ***at 1 MHz offset***. Its a lot worse at 10 KHz, even with a wide control loop its only -100 dBc/Hz at 500 MHz.

What to do?

5. Use a much wider control loop bandwidth. This does limit the step size because in traditional PLL the phase detector reference frequency needs to be significantly higher than the loop bandwidth.

What to Do?

6. Consider using a fractional-N-division synthesizer chip. Vendors and Ulrich Rohde both show the technique can produce much quieter phase noise. In the 2001 edition of his receiver book, Rohde shows the fractional-N-division synthesizer can have 25 to 45 dB less phase noise with the same reference source.

What to Do?

7. Be certain that the noise from the oscillator voltage regulator isn't modulating the oscillator at any frequency. The common 78L family isn't perfectly quiet. F9HX uses one as a noise source to modulate clean oscillators to demonstrate the effects of phase noise. Lots of wide band filter capacitors seem most appropriate. A BIG tantalum and some monolithic types should do. But watch out for piezoelectric dielectrics.

But get ON the air!

73, Jerry, K0CQ

What's next?

The fundamental questions remain.

1. What's too much phase noise in the absence of discrete signals for reciprocal mixing? E.g. how much phase noise can there be without raising the receiver NF and MDS? I'm sure the better the NF the better the phase noise needs to be.

2. Is that maximum phase noise level affected by system IF bandwidth?

Project in the works.

Wenzel links to a pink noise generator using a pair of PIC16F84A. I have board, chips, source code, and programming tools. That pink noise at least out to 20 Khz isn't a bad imitation of typical LO phase noise and the FM modulator on my HP8640B has a 250 Khz video bandwidth. So keeping the modulation index low I can emulate any quality of oscillator with the combination.

Project continued

I have had the old fashioned vacuum diode noise generator and audio VTVM for measuring NF up through 432 through the receiver IF, so I can use it to measure a converter's NF at various IF bandwidths. The pain will be that the narrower the IF the more the noise indicator wanders. I may try a true RMS meter that uses a hot resistor and a thermocouple to achieve a slower response. Or I may increase the meter time constant in the HP400E.

Project continued

Overnight I found W7ZOI's July 2008 QEX article on notching the carrier to allow easy phase noise measurements and I have lots of crystals so I can use that to calibrate the modulated HP8640B phase noise. First step now is to find enough bench space to assemble the pink noise box and the crystal carrier notch filter.

January 21, 2009 GNJ