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DEVELOPMENT OF COMPACT RADIO FREQUENCY SOURCES

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Abstract

Our group is developing a family of compact radio frequency sources aiming to cover 50 MHz to 20 GHz with several models. The primary goal is to provide an alternative to using expensive laboratory generators in permanent installations. In addition, we work towards providing a higher specification than similar telecommunications devices as this is a typical requirement in accelerator instrumentation. We take a minimalistic approach with only a network interface planned, assuming that such a device operates remotely in a large facility. An interface is in the works for monitoring and control using EPICS (Experimental Physics and Industrial Control System). In this paper, we present the results of rapid prototyping with XMicrowave components. The first measurements show encouraging phase noise performance and spectral purity.

INTRODUCTION

The aim of our project is to achieve the phase noise and spectral purity performance of a mid-range benchtop radio frequency (RF) generator, albeit at the loss of versatility. This loss is deemed acceptable if the only purpose of the source is to generate a stable signal at a fixed frequency, for example in a local oscillator (LO) application. In these proceeding we are looking at the performance of a signal source based on a low cost frequency synthesizer in comparison with commercially available examples of sources in both compact and benchtop formats.

We will thus be looking at 3 sources: a high quality Rohde and Schwarz SMA 100A [1] benchtop generator, an AtlanTecRF ASG-3000 compact signal source [2] aimed at Communications market, and our source developed around the Analog Devices' ADF4355 [3]. For brevity, these will be called SMA 100A, ASG, and ADF4355 respectively.

ADF4355 FREQUENCY SYNTHESIZER

The ADF4355 chip combines a Phase Locked-Loop (PLL) and a Voltage Controlled Oscillator in one package and allows for the implementation of integer-N and fractional-N PLL frequencies. Apart from a reference frequency, it requires only a handful of external components to operate. A series of internal frequency dividers allows for an operating frequency range of 54 MHz to 4.4 GHz. The ADF4355 chip has programmable output power, RF output mute, and can be controlled by a 3 wire Serial Peripheral Interface (SPI). We are currently using the device at the default loop bandwidth of 20 kHz.

Our implementation employs a budget Raspberry Pi 2040 microcontroller, housed on a W5100S-EVB-Pico by WIZnet [4]. Beside the low cost, this device has the advantage of running MicroPython, which shortens the development cycle compared to a classic microcontroller. We chose a board incorporating the Ethernet interface, as this is our preferred way of communicating with the device. ADF4355 along with other variable components following it are controlled using the GPIO pins of the microcontroller via SPI. A custom software stored in the FLASH memory of the board is initialised at the powerup and waits for an external command. Commands are sent via the Ethernet port, which are at the moment limited to changes in output frequency and power. The controller then calculates the required settings for the synthesizer chip and programs its registers accordingly.

Behind the scenes the changes of frequency and power settings trigger additional adjustments to filter banks and variable attenuators aimed at optimising the harmonics content and equalising the signal at different frequencies.

For the first prototype, we used rapid microwave prototyping blocks provided by XMicrowave [5]. A convenience PCB hosts the W5100S-EVB-Pico along with a few ancillary components, and simplifies connections to the RF blocks. A 3D printed enclosure houses all the elements of the prototype, including a high quality reference source.

PERFORMANCE COMPARISON

We compare the performance of the three sources by analysing their Phase Noise Measurements (PNM) at three different "inconvenient" fractional frequencies: 1033.33 MHz, 1879.68 MHz, and 2998.75 MHz. We also look at the spectral purity of each of the three sources. The data for these measurements was taken on a Rohde and Schwarz FSW 50 with a resolution bandwidth (RBW) of 20 kHz and a video bandwidth (VBW) of 30 Hz.

Phase Noise Performance

In Figure 1 we can see the PNM for each of the three sources at an output frequency of 1033.33 MHz. Looking at the phase noise for the ASG, blue line, we can see that the phase noise is relatively high at low frequency offsets. As the frequency offset becomes larger, the PNM decreases and plateaus. Next we can see the appearance of spurs, which increase the phase noise. Finally, the phase noise rolls off to about −105 dBc/Hz.

The black line shows the phase noise performance of the AF4355 frequency synthesizer. There the phase noise starts low at about −80 dBc/Hz, and decreases to about −105 dBc/Hz. Then it increases to about −90 dBc/Hz at the edges of the PLL bandwidth before steeply decreasing to −140 dBc/Hz at a higher frequency offsets.

Lastly, we have the phase noise performance of the SMA 100A in red. This source starts with a low phase noise of

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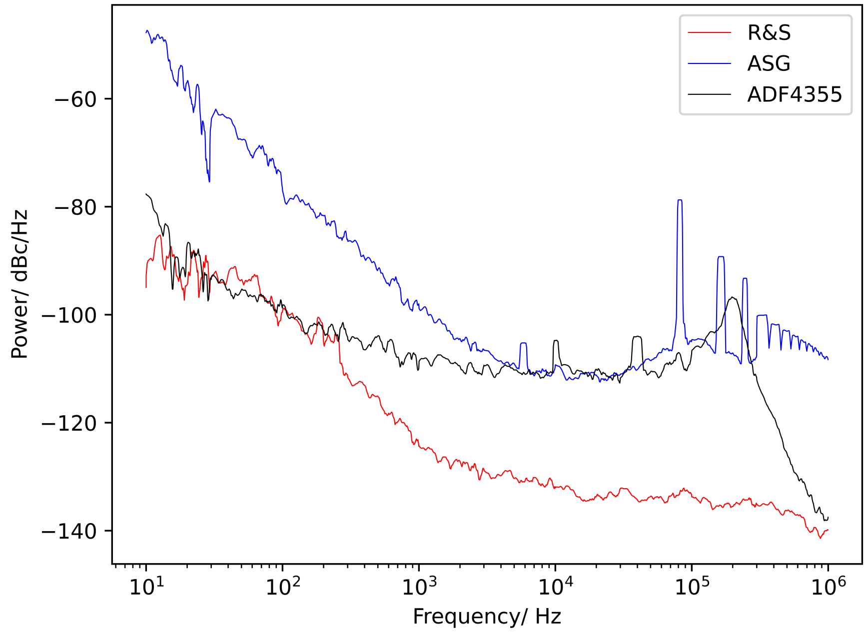

Figure 1: Phase Noise Measurement for the three sources at a frequency output of 1033.33 MHz.

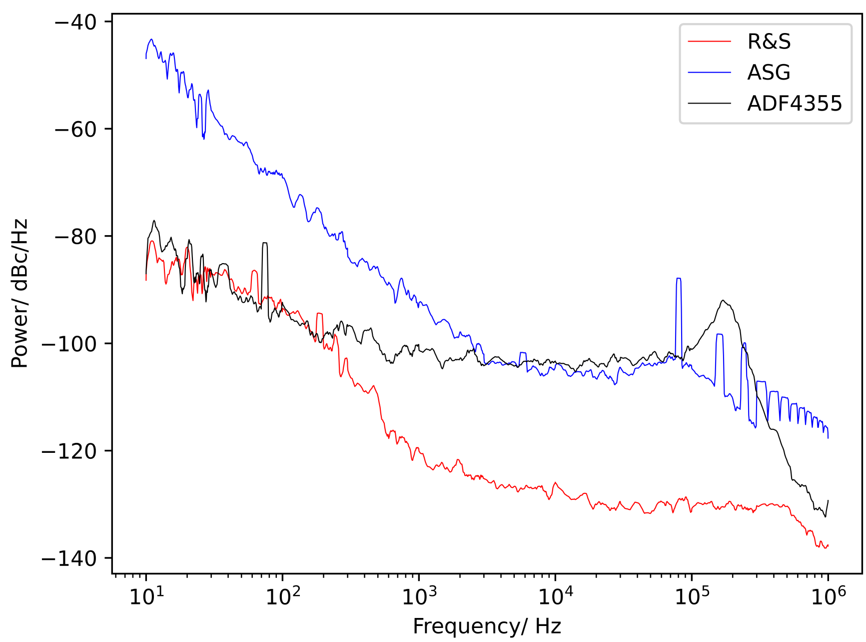

Figure 2: Phase Noise Measurement for the three sources at a frequency output of 1879.75 MHz.

−90 dBc/Hz, which decreases steadily to −140 dBc/Hz at larger offsets.

The pattern repeats for the PNMs taken at the two other chosen frequencies. Figure 2 is the frequency output of 1897.75 MHz and Figure 3 is the frequency output of 2998.68 MHz.

To quantify the phase noise performance of the three sources, we calculated the phase jitter of all three sources based on the measurements at each of the chosen frequencies. Here, in Table 1, we show the phase jitter for a frequency output of 2998.68 MHz. For a frequency output of 1033.33 MHz, the timing jitter for the SMA 100A, ADF4355, ASG is 45.27 fs, 404.4 fs, and 2265 fs respectively. For a frequency output of 1879.75 MHz the timing jitter for the SMA 100A, ADF4355, ASG is 49.69 fs, 394.7 fs, and 1582 fs respectively.

Table 1: RMS Phase Jitter Measurements for a Frequency Output of 2998.68 MHz

Device	**Δt, fs**	**$\Delta\phi$, rad**	**$\Delta\phi$, deg**
SMA 100	39.95	0.752	0.042
ADF4355	303.60	5.72	0.327
ASG	1266	23.85	1.366

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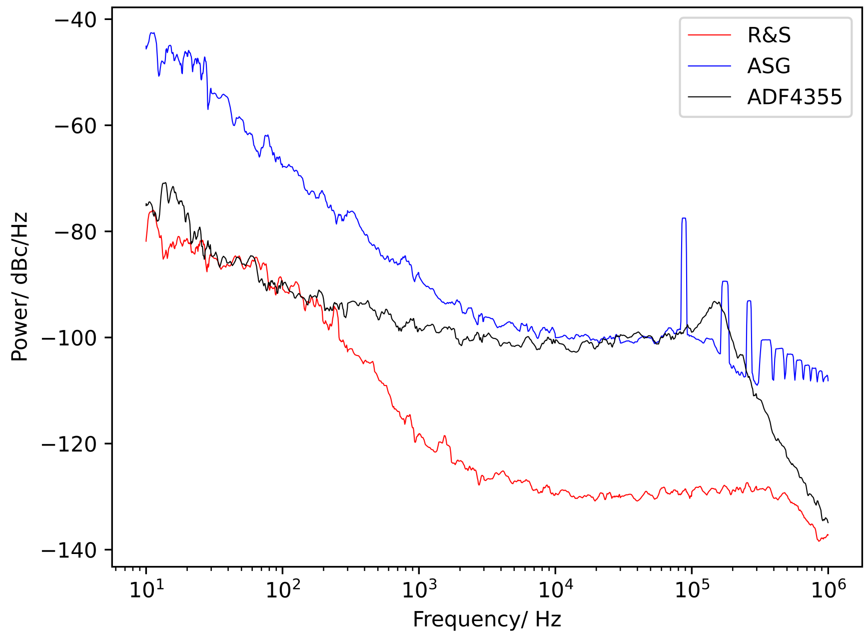

Figure 3: Phase Noise Measurement for the three sources at a frequency output of 2998.68 MHz.

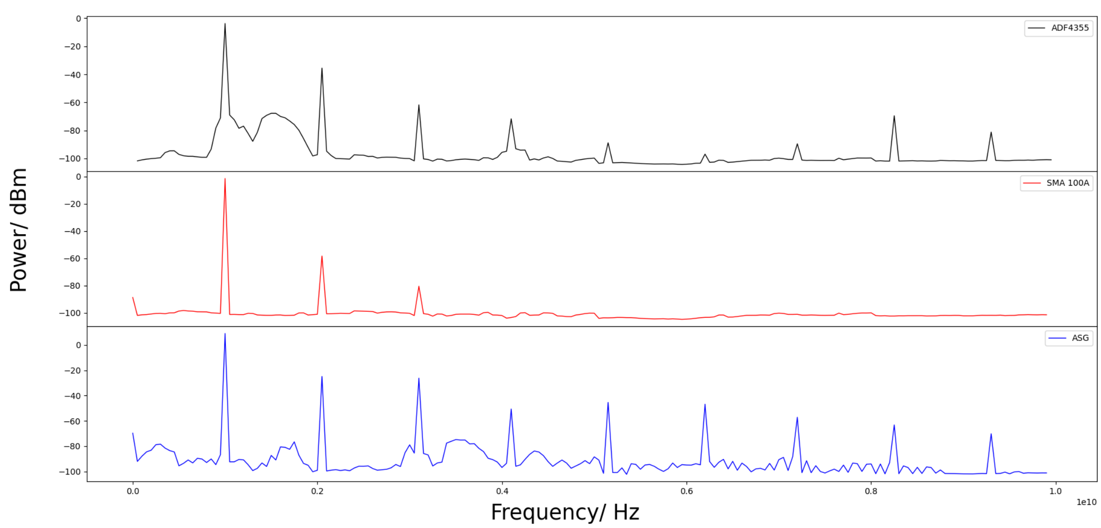

Figure 4: Spectral output of the three sources for a frequency output of 1033.33 MHz.

Clearly, our synthesizer performs well in phase noise measurements sitting firmly between in the targeted niche between the typical representatives of laboratory and compact sources. Further improvements, such as the optimisation of the PLL bandwidth, may still be possible.

Spectral Performance

In Figure 4, one can see the spectrum of the three sources at a frequency output of 1033.33 MHz measured up to 10 GHz. The top plot shows the spectral output of our ADF4355, the middle plot for the SMA 100A, and the last plot shows the spectral output of the ASG. Once again, the spectral output of ADF4355 is superior compared to the compact source presenting a much cleaner spectrum with fewer strong harmonics and boundary spurs. The data for these measurements was taken on a Rohde and Schwarz FSW 50 with a resolution bandwidth (RBW) of 20 kHz and a video bandwidth (VBW) of 30 Hz.

PERFORMANCE CONCLUSION

In phase noise performance our ADF4355 based frequency synthesizer is comparable to the Rohde and Schwarz SMA 100A at lower frequencies off sets (10 Hz – 120 Hz), while SMA 100A clearly outperforms it in a wider range. However, we achieved the goal of reaching a higher specification compared to the ASG signal generator with a 4-5 times lower integrated phase noise. With the present spec, our source can be applied in all but the most demanding local oscillator applications. Our goal is achieving sub-100 fs jitter, this may still be possible with some optimisation of the

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PLL. The ADF4355 based source also achieves a reasonable spectral purity with the first harmonic at about −40 dBc and strongly suppressed higher harmonics.

APPLICATIONS

There are number of potential applications for a compact high frequency source within accelerator physics [6]. Providing test or local LO signals for up/down-converters are typical applications. Remote control capability and compact size of our design are important in the busy environment of a particle accelerator.

Outside of particle accelerator labs, beside potential usefulness as a general laboratory or communications equipment, such a source could be useful is in building quantum computing systems [7]. Qubit Control and manipulation is achieved at RF frequencies. RF sources provide excitation and LO signals for the readout. The phase noise requirements are typically higher than for communications systems.

CONCLUSION

Our first prototype of a compact RF source is en route to achieving its goals in terms of high signal quality, outperforming commercially available budget options and in some aspects approaching the specs of expensive benchtop generators. Further improvements may still be possible with minimal changes to the current hardware. In the next stages of this project we will focus on integrating the system towards a pre-production prototype that could be manufactured in larger quantities. Similar models covering different frequency ranges are also in the works.

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