# Reference Frequency Distribution System

Whitham D. Reeve

---

## 1. Introduction

This article is related to my previous articles, **Using the SDRPlay SDR Receivers with an External Frequency Reference** {Reeve20} and **10 MHz Reference Distribution Amplifier** {Reeve17}, and describes a 6-port active Reference Frequency Distribution System (RFDS) that is usable with any single input frequency from below 5 MHz to above 100 MHz (figure 1). The RFDS can be equipped so that it is driven by an external precision frequency source or by an optional internal Mini-GPS Reference Clock module to provide an integrated precision reference frequency source with distribution (figure 2).

Figure 1 ~ Front view of the Reference Frequency Distribution System showing the six outputs and an optional GPS antenna resting on top. The rear panel, not seen here, holds the reference or GPS antenna input, an On-Off switch, power indicating LED and coaxial dc power jack. The enclosure dimensions are 1.77H x 4.27W x 6.30L in (45 x 108.5 x 160 mm) and weight is 1 lb (0.5 kg). Image ©2020 W. Reeve

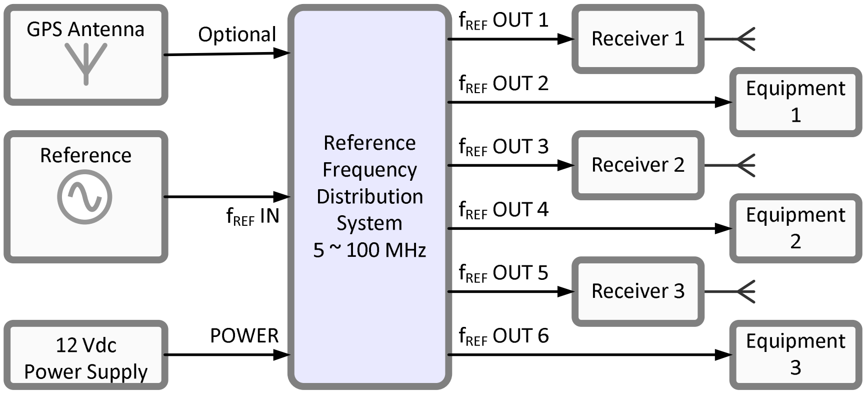


Figure 2 ~ Application of the Reference Frequency Distribution System. The external reference source or optional internal Mini-GPS Reference Clock with GPS antenna drives the distribution system. All outputs operate at the same frequency. Image ©2020 W. Reeve

The active distribution circuits used in the RFDS have no intentional filtering, which means that if the reference frequency source is distorted (includes spurious signals and harmonics), that distortion will be passed through to the outputs. The RFDS itself adds negligible distortion (measurements are given in section 4).

Most commercial and amateur reference frequency distribution systems operate only at 10 MHz and have a narrow bandwidth of a couple percent of the carrier frequency; thus, they cannot be used with many types of receivers and observatory equipment. For example, the SDRPlay receivers use 24 MHz and the DG8SAQ VNWA-series vector network analyzers use 36 MHz. The AirSpy, Icom R-8600 and RFSpace receivers use 10 MHz (the RFSpace SDR-14, which has no factory provisions for an external reference source, can be modified to use 66.66666 MHz). The RFDS operates on any single frequency, so if more than one reference frequency is required in an observatory, say 10 and 24 MHz, then a Reference Frequency Distribution System is required for each one.

---

## 2. Design

I was inspired by an article in the April 2020 issue of Silicon Chip magazine [SiliconChip] that described a *Frequency Reference Signal Distributor* meant for 10 MHz, but it used wideband components that I could see would easily support a range of lower and higher frequencies. The original design was based on the Maxim Integrated MX4450 integrated circuit operational amplifier with 210 MHz frequency range. I also used this amplifier in the RFDS but modified its application to more closely comply with the amplifier's datasheet recommendations.

I also modified the internal power supply and added input overcurrent and overvoltage circuitry. The original design used a resistive voltage divider with a linear voltage regulator to produce 7 V operating voltage ($V_{cc}$) for the active circuits. My design operates directly at the voltage produced by an 8 V low dropout (LDO) linear voltage regulator. I designed the PCB to fit in common extruded aluminum enclosures and to also accommodate an optional Leo Bodnar Electronics Mini-GPS Reference Clock module as an internal reference source.

I used surface mounted devices (SMD) throughout except for the power and LED connector headers and voltage regulator ICs. The SMD resistors and capacitors are size 1206 (0.12 x 0.06 in), so are relatively easy to handle. The MAX4450 amplifiers are available in microminiature SC70 (SOT323) and larger SOT23 versions – I used the larger version, one per channel. The trace lengths to the amplifier inputs are short and direct but they are not identical; measurements shown in section 4 indicate there was no phase differential penalty for this configuration. The traces from the amplifier outputs and their associated circuits are identical. The PCB layout (figure 3) was prepared with Target 3001! printed circuit design software.

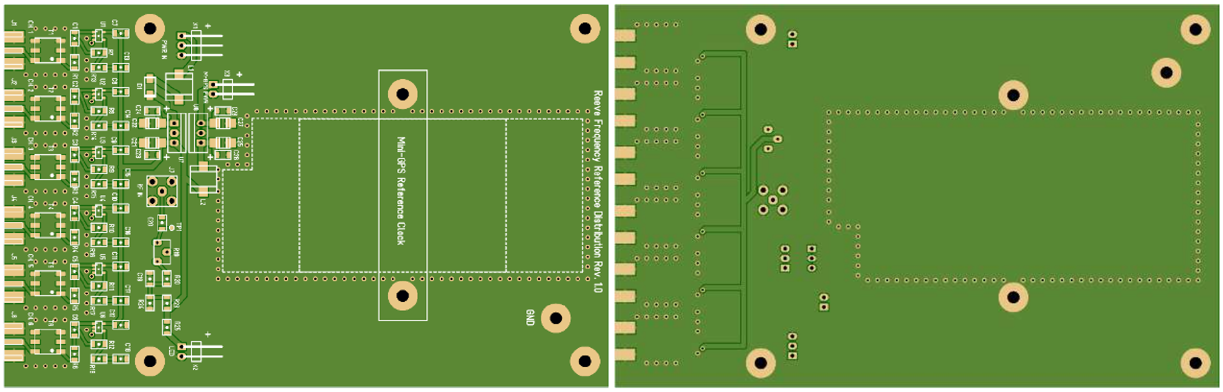


Figure 3 ~ Prototype printed circuit board top and bottom images produced from the PCB Gerber files and shown at 50% scale. The PCB is 100 x 160 mm and will fit many extruded aluminum enclosures, such as the Box Enclosures model B3-160. I equipped the PCB with four 3.2 mm diameter holes for mounting in an enclosure that does not have built-in PCB rails. The space dedicated to the Mini-GPS Reference Clock is seen in the silkscreened open area. In the prototype this unit was mounted with a brass strap fastened with screw fasteners. However, for production, I changed the PCB to use oblong holes so that small nylon tie wraps may be used in place of the metal strap and screws. The PCB may be used without the Mini-GPS Reference Clock and cut in half to fit an 80 mm long enclosure (such as the Box Enclosures B3-080). Image ©2020 W. Reeve

Operation is described in the following paragraphs and simplified block diagram (figure 4). The RFDS uses a 2-stage power supply with nominal 12 Vdc input. The input powering voltage to the RFDS can range from about 10 V minimum to 15 V maximum. Higher input voltages result in higher heat dissipation in the first-stage voltage regulator. The first stage supplies 8.0 V to the active circuits and power indicating LED and the second stage supplies 5.0 V to the optional Mini-GPS Reference Clock. The 8 V LDO (low dropout) regulator output is connected to a resistance voltage divider that provides 4.0 V bias to each amplifier so that their inputs operate symmetrically between the power (Vcc) and ground rails. All inputs and outputs are dc isolated.

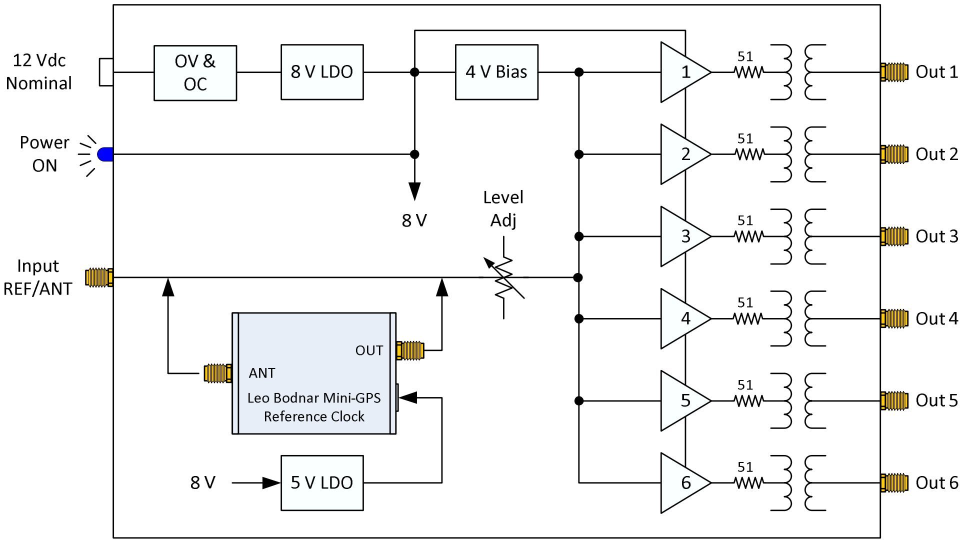


Figure 4 ~ Reference Frequency Distribution System simplified block diagram. The active circuits are powered by the 8 V LDO and the optional Mini-GPS Reference Clock is powered by the 5 V LDO. The Mini-GPS Reference Clock may be easily added or removed as needed. The amplifier outputs are connected to the coupling transformers through capacitors (not shown) for dc isolation and through 51 ohm resistors for impedance matching. Image ©2020 W. Reeve

The RF input from an external reference source or, optionally, from an internal Mini-GPS Reference Clock is capacitor coupled to a potentiometer for output level adjustment. The potentiometer slider is connected to the paralleled non-inverting inputs of six operational amplifiers. The amplifiers are configured for a voltage gain of 2. The overall power gain of the RFDS is adjustable from –7 to +3 dB (see section 4 for tests and measurements). Each amplifier output is capacitor coupled to a 1:1 wideband transformer through a 51 ohm resistor, which sets the output impedance of each channel to a nominal 50 ohms. Note that most devices that use a precision frequency source can accept a range of input voltages or powers so it should not be necessary to increase or decrease the level with an external amplifier or attenuator.

The Mini-GPS Reference Clock, if equipped, is hidden from access and view when the PCB is installed in an enclosure. This means that the reference frequency must be setup with the PCB removed from the enclosure so that the Mini-GPS Reference Clock can be connected to a PC with a USB cable. For setup, the Mini-GPS Reference Clock is disconnected from its power source on the PCB and temporarily connected to a Windows PC with a separate cable. At this point the Reference Clock is powered and controlled by the PC. After setup is completed, the Reference Clock is reconnected to the PCB. The LED on the Mini-GPS Reference Clock that indicates GNSS satellite fix is invisible when the PCB is installed in an enclosure, so a peephole was drilled in the enclosure end panel to observe the LED.

## 3. Construction

Construction is straight forward. The surface mounted devices are installed in the following order: Amplifiers, capacitors, resistors, and SMA-F bulkhead mount connectors. To ensure alignment of the SMA connectors on the PCB edge, I first cut holes in the end-panel and then mounted the connectors on it. I aligned the connectors on the PCB and checked that the assembly would line up properly when installed in the enclosure. I then soldered the connector pads. The through-hole components such as the voltage regulators and adjustment pot were installed last (figure 5).

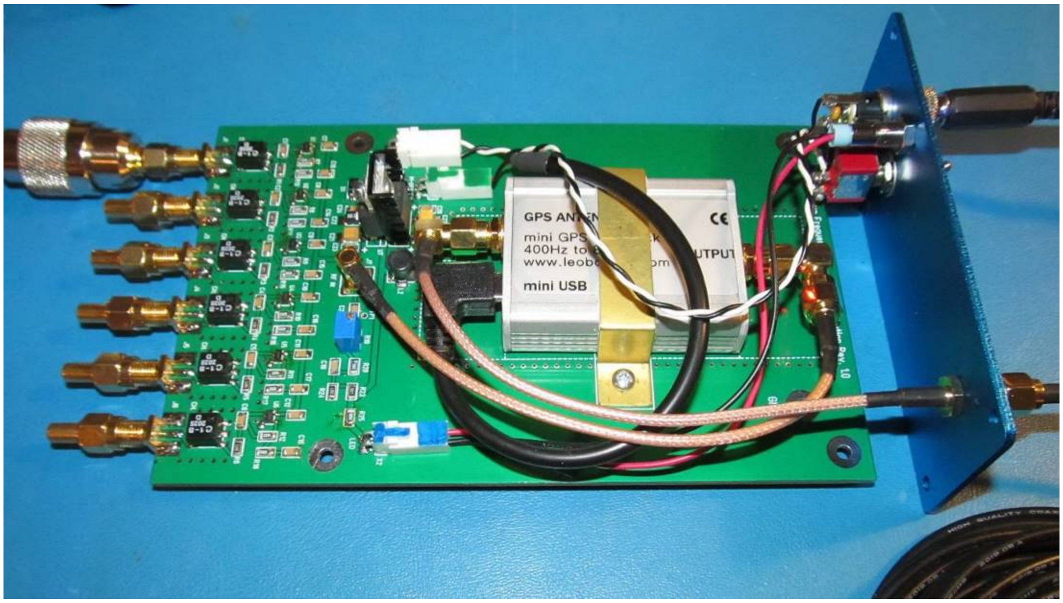


Figure 5 ~ Prototype of the Reference Frequency Distribution System with rear panel while under test. The SMA-F connectors for the six outputs are seen on the left edge of the PCB; channel 1 (upper-left) is connected to the spectrum analyzer for measurements and channels 2 – 6 have 50 ohm terminations. The output transformers are immediately to the right of the RF connectors, and the six identical amplifier circuits are to the right of the transformers. All components are grouped so that the PCB may be cut down and used in a shorter enclosure if the Mini-GPS Reference Clock is not equipped. It is shown here mounted with a metal strap (see text). The power and LED interfaces use friction lock connectors. The prototypes used an MCX-F socket on the PCB (seen here just to the left of the Mini-GPS Reference Clock antenna connection) for connecting the reference source input. This connector was replaced with an SMA-F connector in the production versions. Image ©2020 W. Reeve

I assembled the rear end panel with the power switch, filter capacitors, polarity guard diode, power indicating LED, locking-type coaxial power jack and SMA-F bulkhead mount connector for the external reference source input or GPS antenna. A cabling diagram clarifies the various connections to the PCB (figure 6). Drawings of the front and rear panels show the external controls and connections (figure 7).

The PCB assembly was installed in a Box Enclosures B3-160 extruded aluminum enclosure with PCB rails. White on clear labels were applied to the blue end-panels. Total parts cost including the PCB, enclosure and shipping but not including the Mini-GPS Reference Clock is approximately 170 USD.

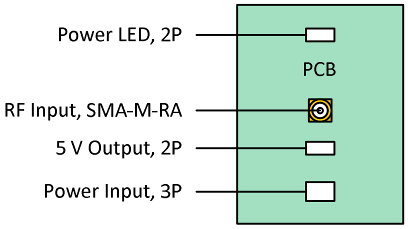


Figure 6 ~ PCB cabling diagram. The RF input uses a threaded RF connector and all other connectors use nylon, polarized, friction-lock wire housings. The connection labeled 5 V Output is for the optional Mini-GPS Reference Clock. The other wire connections go to the rear panel. The RF input connection also goes to the rear panel unless the Mini-GPS Reference Clock is equipped. The power input connector has 3 contact positions to differentiate it from the others; only 2 positions are used. Image ©2020 W. Reeve

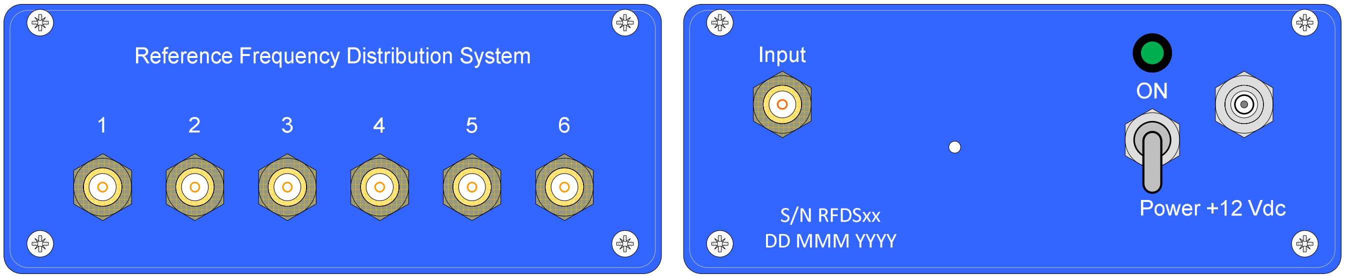


Figure 7 ~ RFDS front and rear end panels. Power is supplied through a locking-type 2.1 x 5.5 mm coaxial dc power jack and a toggle switch on the right side of the rear panel. The Input SMA-F connector on the left side of the rear panel is used for the reference source input or GPS antenna depending on if the Mini-GPS Reference Clock is equipped. A 2 mm diameter peep-hole is provided on the rear panel between the power switch and Input connector to allow viewing of the status LED on the Mini-GPS Reference Clock. Image ©2020 W. Reeve

---

## 4. Tests & Measurements

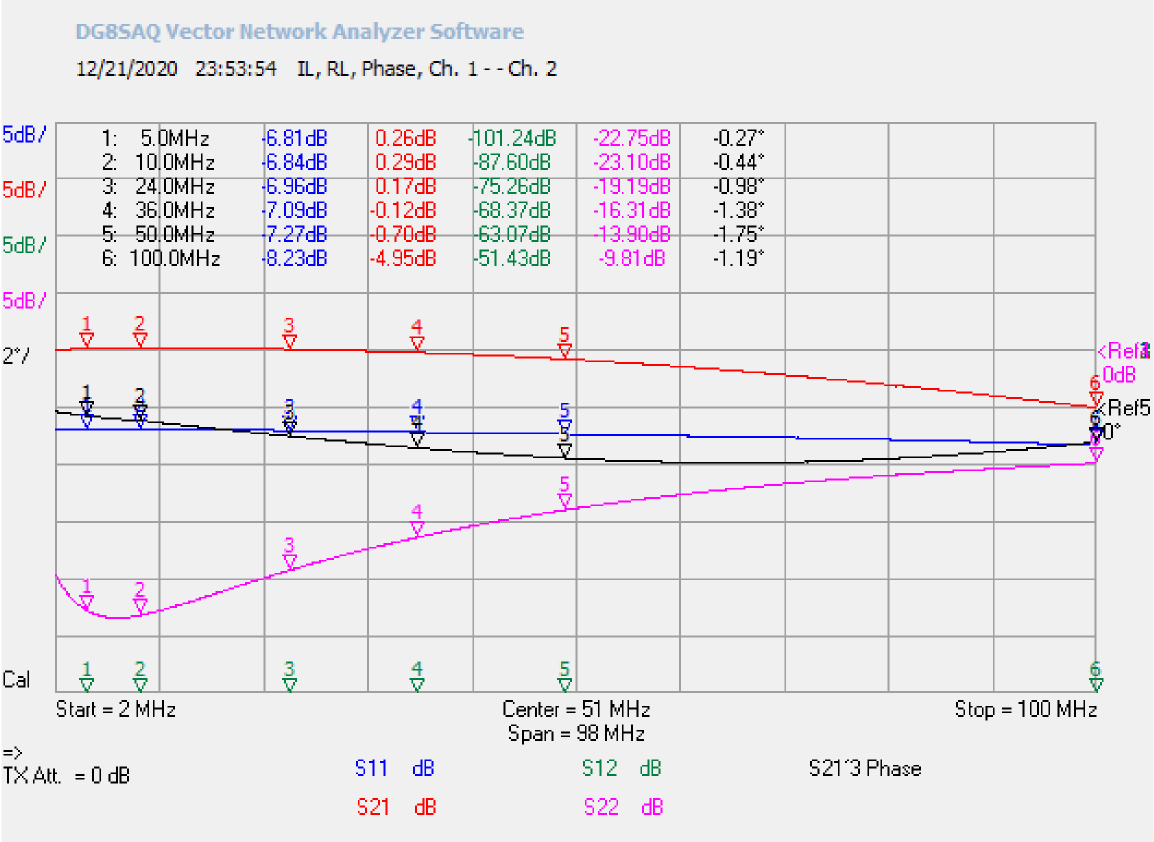
I used a variety of test equipment to make the RF measurements including a Siglent SSA3302X spectrum analyzer, Keysight N9917A Microwave Analyzer in Network Analyzer mode, a DG8SAQ VNWA-3SE vector network analyzer, Siglent SSG3032X RF signal generator and Siglent SDS2302X oscilloscope. The N9917A alone is capable of all the RF measurements, except the waveform, but I used this project as an opportunity to compare the results from other test sets. I used a Siglent SPD3303X power supply to power the RFDS for all measurements.

With 12.0 Vdc input voltage, the RFDS load current without the internal Mini-GPS Reference Clock and without an input signal is about 72 mA increasing to 81 mA with a 0 dBm input signal. With the Mini-GPS Reference Clock installed but before its receiver achieves a satellite fix, the total load is about 305 mA. When the receiver achieves a fix and is tracking satellites, the total load current increases to about 395 mA.

During the RF measurements of each channel, all unused outputs were terminated with 50 ohms. I also made a complete set of measurements with no terminations on the unused outputs and found no measurable differences. Nevertheless, good practice is to always terminate all unused RF ports.

I adjusted the prototype to provide nominal 0 dB power gain from the input connector to the output connectors at 10 MHz (level adjustments could be made at any desired frequency). These measurements were made with 10 dB attenuators on the signal generator output and spectrum analyzer input to ensure impedance matching (these attenuations are included in the instrument normalization). There are slight gain variations across the frequency range with some roll off between 50 and 100 MHz (figure 8). The measurements of phase difference between channels showed only a fraction of a degree up to 24 MHz and < 2° to 100 MHz; thus, the outputs can be considered *coherent*.

The RFDS outputs are well-matched to 50 ohms impedance with a return loss better than 14 dB from 5 to 50 MHz, equivalent to a VSWR better than 1.5:1. The best return loss is approximately 24 dB between 5 and 10 MHz. The input return loss is not nearly as good at about 7 dB, equivalent to 2.6:1 VSWR. The input return loss measurements were made with the input potentiometer set to provide 0 dB power gain.


DG8SAQ Vector Network Analyzer Software

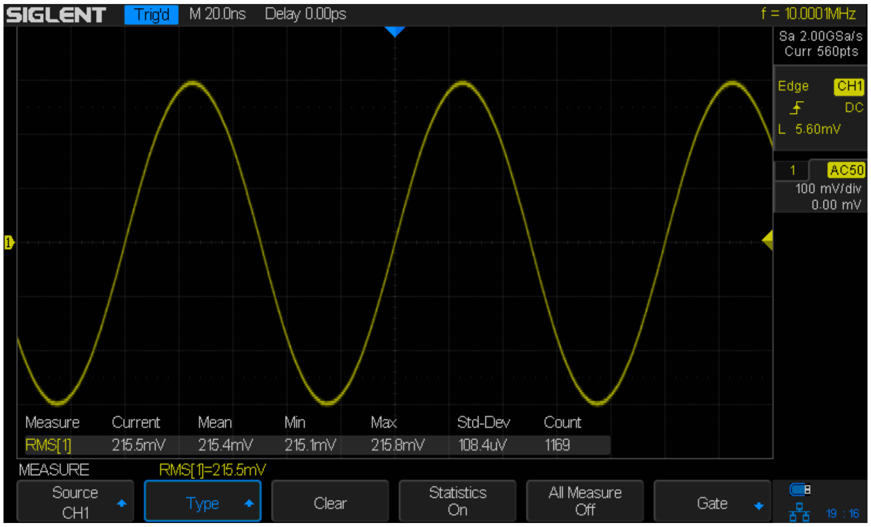
12/21/2020 23:53:54 IL, RL, Phase, Ch. 1 - - Ch. 2

| | | | | | |
|---|---|---|---|---|---|
| 1: 5.0MHz | -6.81dB | 0.26dB | -101.24dB | -22.75dB | -0.27° |
| 2: 10.0MHz | -6.84dB | 0.29dB | -87.60dB | -23.10dB | -0.44° |
| 3: 24.0MHz | -6.96dB | 0.17dB | -75.26dB | -19.19dB | -0.98° |
| 4: 36.0MHz | -7.09dB | -0.12dB | -68.37dB | -16.31dB | -1.38° |
| 5: 50.0MHz | -7.27dB | -0.70dB | -63.07dB | -13.90dB | -1.75° |
| 6: 100.0MHz | -8.23dB | -4.95dB | -51.43dB | -9.81dB | -1.19° |

Figure 8 ~ The DG8SAQ VNWA-3SE vector network analyzer produced the measurements shown here for the input and channel 2 output. All channels showed the same results within a small fraction of a unit. The vertical scales are 5 dB/div except phase, which is 2° /div. The reference (0 dB or 0°) position for each trace is the 6th division from the bottom except for phase, which is the 5th division. The marker table at top shows the measurements at specific frequencies. S11 (blue trace) is the input reflection coefficient expressed in dB and equivalent to return loss. S21 (red trace) is the forward transmission coefficient from input to output expressed in dB and equivalent to transmission loss or gain. S12 is the reverse transmission coefficient in dB output to input (off scale but shown in the marker table), and S22 is the output reflection coefficient in dB. The trace marked S21'3 Phase (black trace) is the phase difference in degrees between the channel 1 and channel 2 outputs.

I would expect some variation in the input return loss with different settings of the potentiometer, but I did not measure it. The inferior matching on the input is the result of its simple design. An improved input design would use an impedance matching transformer along with a resistor divider network optimized for 50 ohms impedance. This would set the gain to a fixed, non-adjustable value. The system gain also can be altered by changing the resistor feedback network on the amplifiers. However, higher gain configurations have reduced bandwidth so the gain cannot be increased without penalty; the MAX4450 datasheet provides guidance.

An oscilloscope showed no obvious distortion in the RFDS output waveform (figure 9), so I examined the input and output signals with the spectrum analyzer. Distortion measurements were made by first examining the signal generator 10 MHz output (which would be the RFDS input) with the spectrum analyzer out to the 10th harmonic (100 MHz). The signal generator produced low-level spurious signals and harmonics at 15, 20 and 30 MHz (figure 10.a), amounting to a total harmonic distortion (THD) of approximately 0.69%. The signal generator was then reconnected to the RFDS and the RFDS output was viewed with another trace (figure 10.b). In this case, there were small changes in some of the existing harmonics and additional low-level harmonics appeared. However, the total harmonic distortion on the output, which includes input distortion products, was materially unchanged at 0.68%. Commercial distribution amplifiers that I have used in the past typically specify total harmonic distortion < 1%, so the RFDS performance is comparable. Note that, although I used marker values from spectrum analyzer measurements to determine distortion products, I could have used the FFT math function in the oscilloscope to measure them.



M 20.0ns Delay 0.00ps f = 10.0001MHz

Sa 2.00GSa/s
Curr 560pts

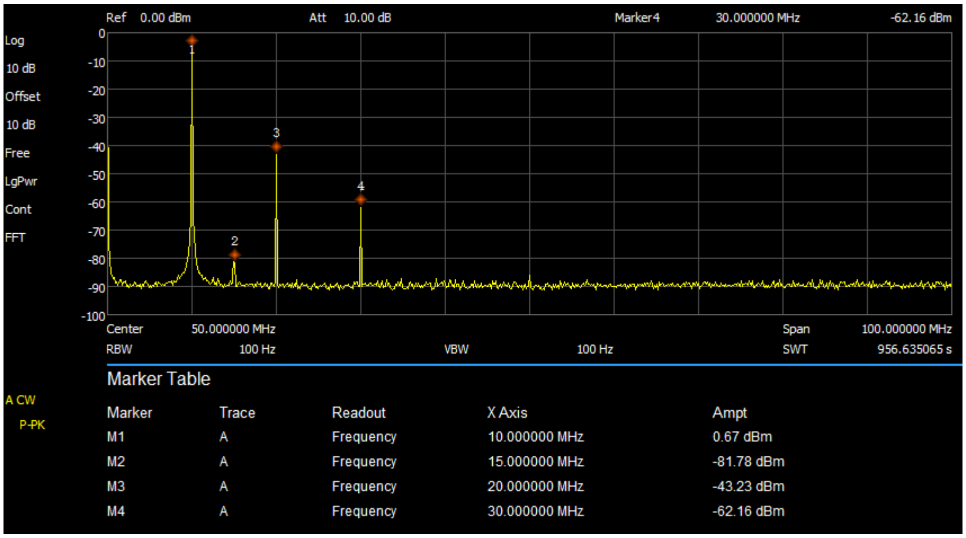
Edge CH1 DC L 5.60mV

1 AC50 100 mV/div 0.00 mV

| Measure | Current | Mean | Min | Max | Std-Dev | Count |
|---|---|---|---|---|---|---|
| RMS[1] | 215.5mV | 215.4mV | 215.1mV | 215.8mV | 108.4uV | 1169 |

MEASURE RMS[1]=215.5mV

Figure 9 ~ The RFDS output displayed on the oscilloscope shows no obvious distortion. The scope is set to provide a 50 ohm termination. The vertical scale is 100 mV/div and the measured rms voltage, shown in the table below the trace, is 215 mV.



Ref 0.00 dBm Att 10.00 dB Marker4 30.000000 MHz -62.16 dBm

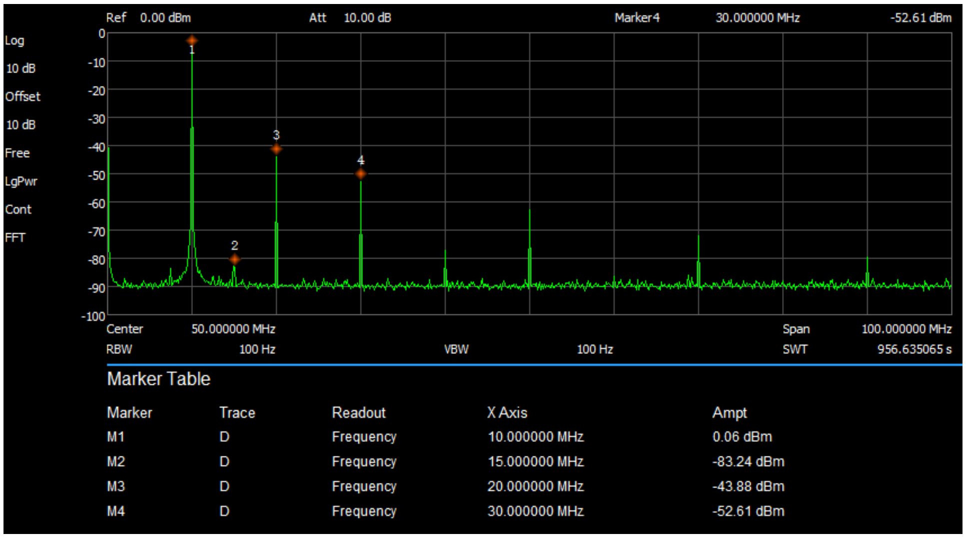
Center 50.000000 MHz Span 100.000000 MHz

RBW 100 Hz VBW 100 Hz SWT 956.635065 s

Marker Table

| Marker | Trace | Readout | X Axis | Ampt |
|---|---|---|---|---|
| M1 | A | Frequency | 10.000000 MHz | 0.67 dBm |
| M2 | A | Frequency | 15.000000 MHz | -81.78 dBm |
| M3 | A | Frequency | 20.000000 MHz | -43.23 dBm |
| M4 | A | Frequency | 30.000000 MHz | -62.16 dBm |

Figure 10.a ~ Signal generator (RFDS input) distortion measurements from 0 to 100 MHz. Weak 2nd and 3rd harmonics (markers 3 and 4) are present at –44 dBc and lower and a low level (–82 dBc) spurious signal at 15 MHz can be seen (marker 2).



Marker Table

| Marker | Trace | Readout | X Axis | Ampt |
|---|---|---|---|---|
| M1 | D | Frequency | 10.000000 MHz | 0.06 dBm |
| M2 | D | Frequency | 15.000000 MHz | -83.24 dBm |
| M3 | D | Frequency | 20.000000 MHz | -43.88 dBm |
| M4 | D | Frequency | 30.000000 MHz | -52.61 dBm |

figure 10.b ~ RFDS output with the signal generator connected. The spurious signal at 15 MHz (marker 2) has decreased by 1.5 dB and the harmonic at 30 MHz (marker 4) has increased by about 10 dB. Additional harmonics at 40, 60, 70 and 90 MHz have appeared but their levels are below –60 dBc.

---

## 5. Conclusions

The Reference Frequency Distribution System provides six coherent outputs and operates on any single frequency between 5 and 100 MHz. Its parts cost is about 170 USD. An optional internal Mini-GPS Reference Clock may be equipped to provide a GNSS-based reference frequency for system operation, or an external precision frequency source may be used.

---

## 6. References & Weblinks

{Reeve17} Reeve, W., 10 MHz Reference Distribution Amplifier, 2017, available at: http://www.reeve.com/Documents/Articles%20Papers/Reeve_10MHzDist.pdf

{Reeve20} Reeve, W., Using the SDRPlay SDR Receivers with an External Frequency Reference, 2020, available at: http://www.reeve.com/Documents/Articles%20Papers/Reeve_SDRPlay-miniGPS.pdf

[SiliconChip] Kosina, C., Frequency Reference Signal Distributor, Silicon Chip, April 2020

---

**Author:** Whitham Reeve obtained B.S. and M.S. degrees in Electrical Engineering at University of Alaska Fairbanks, USA. He worked as a professional engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and now manufactures electronic equipment used in radio astronomy. He also is a part-time space weather advisor for the High-frequency Active Auroral Research Program (HAARP) and a member of the HAARP Advisory Committee. He has lived in Anchorage, Alaska his entire life. Email contact: whitreeve@gmail.com

**Document information**

Author: Whitham D. Reeve

Revision: 0.0 (Original draft started, 14 Dec 2020)
0.1 (Added RF measurements, 24 Dec 2020)
0.2 (Added distortion measurements, 26 Dec 2020)
0.3 (Added images of completed system, 27 Dec 2020)
0.4 (Completed 1st draft, 28 Dec 2020)
0.5 (Ready for distribution, 02 Feb 2021)

Word count: 3101
File size: 541184