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Digitally Tunable Band-Pass Filter

Computer control tunes this versatile band-pass filter to meet changing requirements.

Band-pass filters have always been important, but new hardware technology has made them even more significant. In environments with large amounts of electromagnetic pollution, this new type of band-pass filter can be very helpful.

To construct the digitally tunable band-pass filter, I used digitally tunable capacitors (DTC). These components have a variable capacitance that can be controlled digitally. The digitally tunable band-pass filter in this article covers a frequency range of 132 MHz to 148 MHz, and can handle up to 26 dBm of RF power. It can be integrated into different projects, including software defined radio (SDR) projects, where the band-pass filters are of fundamental importance to the end result.

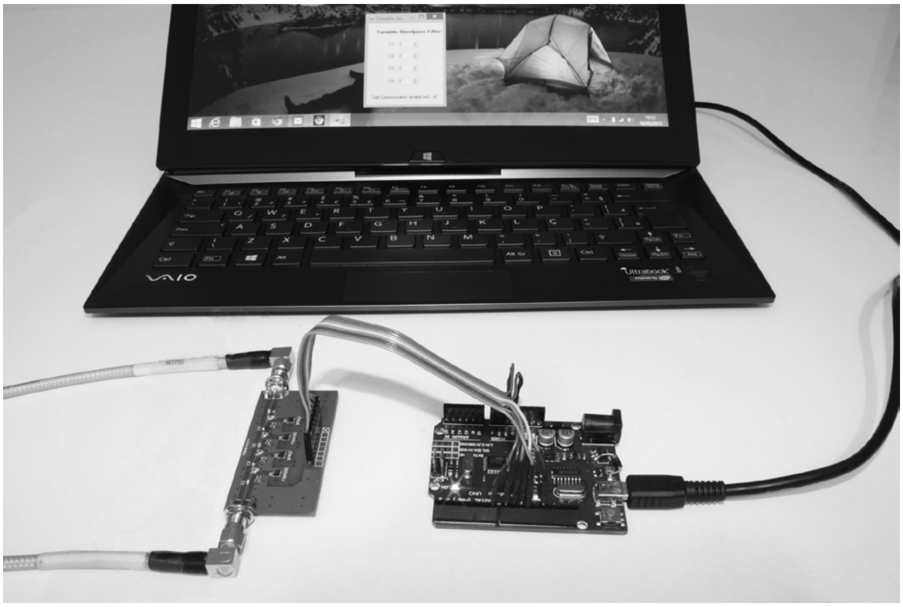
Digitally Tunable Capacitors (DTCs)

The key parts of the band-pass filter described in this article are digitally tunable capacitors (DTCs), which are made up of several high-*Q*-factor metal-insulator-metal (MIM) capacitors, which are digitally controlled FET switches. Figure 1 is a functional block diagram of a DTC.

The DTC used in the design of this project is the Peregrine PE64102, which has a capacitance range of 1.88 pF to 14.0 pF in steps of 391 fF, totaling 32 states that are controlled with 5 bits through a serial peripheral interface (SPI) bus.[1] The Peregrine PE64102 works at 100 MHz to 3 GHz, and can handle up to 26 dBm of RF power.

Design the Filter

Basically, a band-pass filter is used to attenuate all signals having frequencies out-



The Computer, Arduino Uno and band-pass filter circuit board.

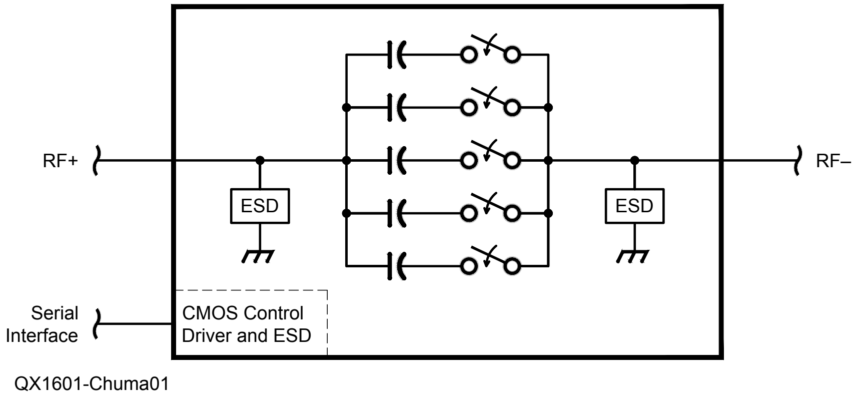


Figure 1 — This is a functional block diagram of the digitally tunable capacitors.

[1] Notes appear on page 8

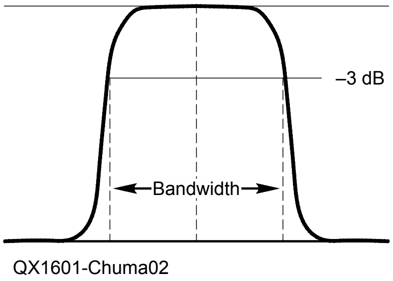


Figure 2 — This is an idealized response curve of a band-pass filter.

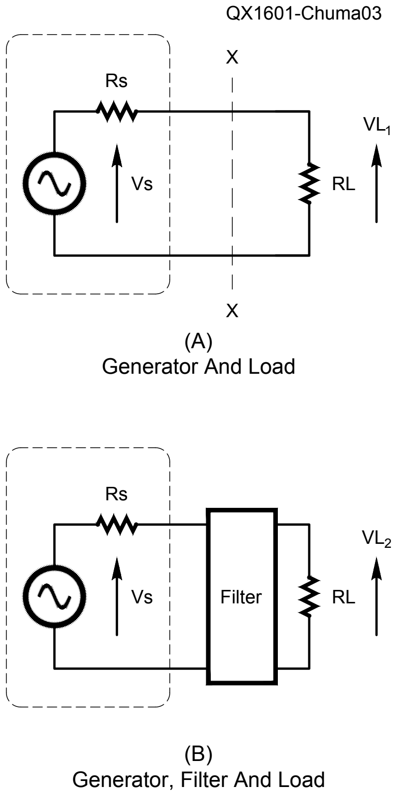
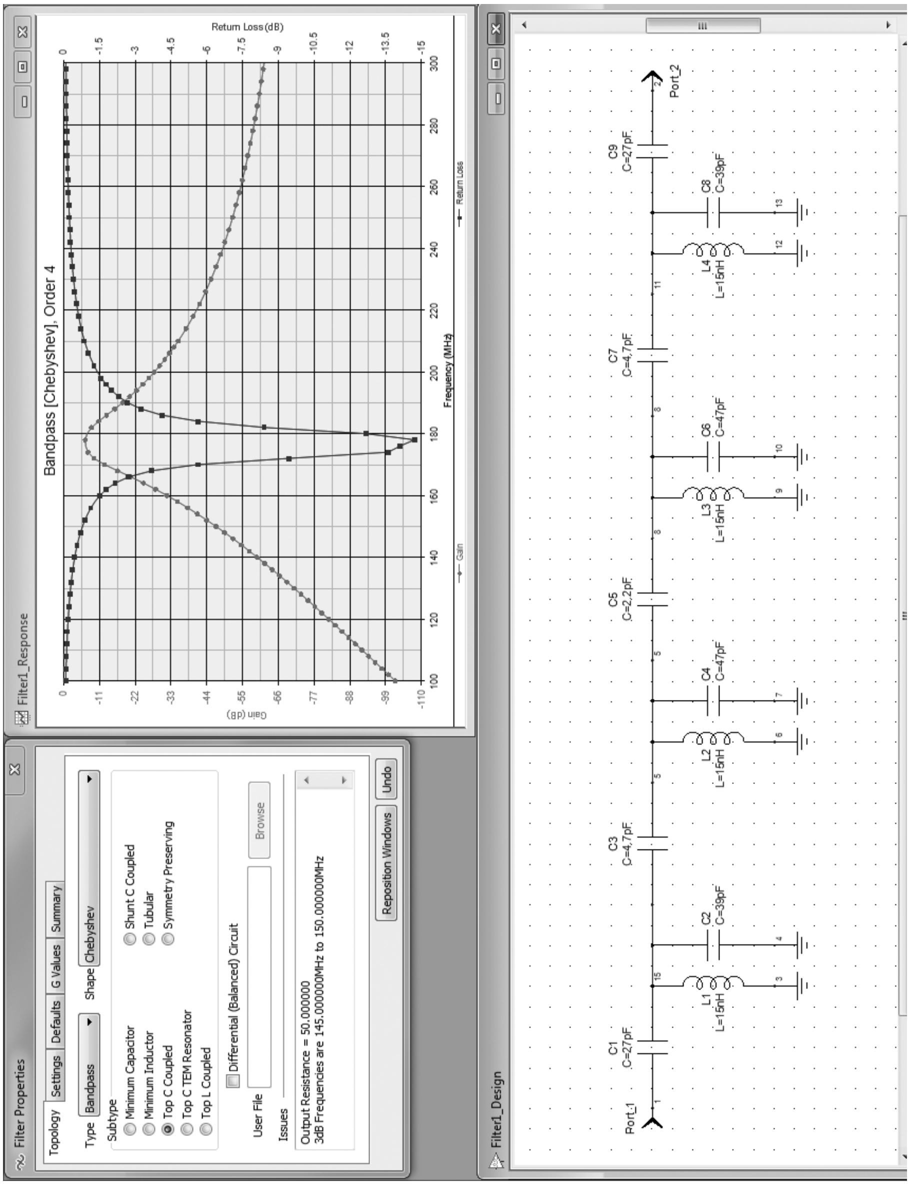


Figure 3 — Here is a block diagram that explains filter insertion loss.



Filter Properties

Topology | Settings | Defaults | G Values | Summary

Type Bandpass Shape Chebyshev

Subtype
○ Minimum Capacitor
○ Minimum Inductor
● Top C Coupled
○ Top C TEM Resonator
○ Top L Coupled
○ Shunt C Coupled
○ Tubular
○ Symmetry Preserving

□ Differential (Balanced) Circuit

User File

Issues

Output Resistance = 50.000000
3dB Frequencies are 145.000000MHz to 150.000000MHz

Figure 4 — This is a screen shot of the filter simulation using the Agilent *Genesys 2010* software.

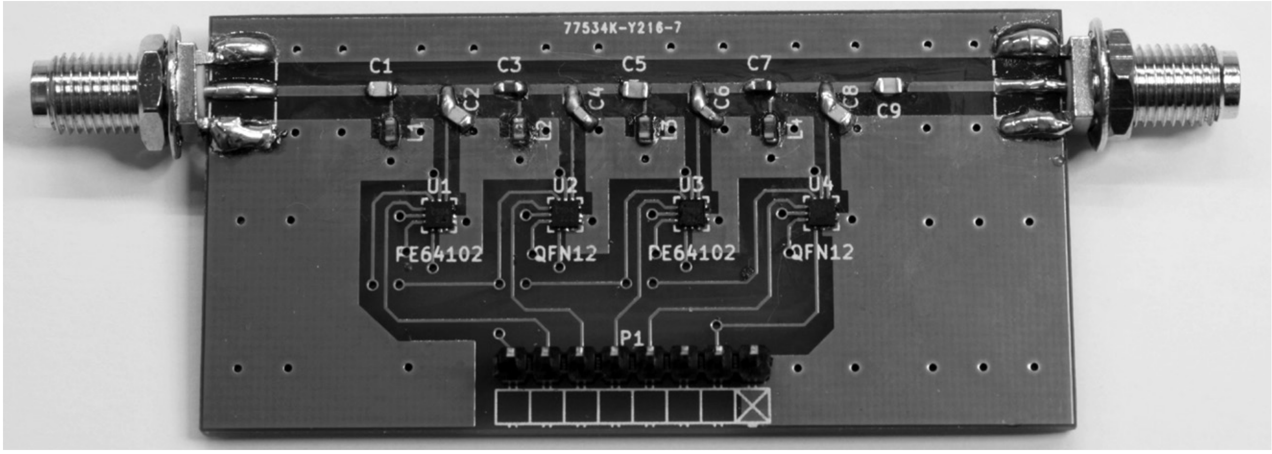


Figure 5 — This photo shows the completed filter circuit board.

side the band of interest. Figure 2 shows the frequency response of a real band-pass filter, where f_c is the center frequency and the bandwidth is the difference between frequencies f_1 and f_2, where the attenuation is 3 dB compared with the magnitude of f_c.

To develop a band-pass filter, we need to know several filter details, such the center frequency, bandwidth, terminating resistance, type of filter response (Butterworth, Chebychev, Elliptical, and so on), and filter order. With these parameters, we can design our filter using simulation software or through manual calculations (hard work).

Several criteria are used to measure the performance of a filter, but the ones used most are the insertion loss and return loss. Insertion loss is the loss of signal power resulting from the insertion of a filter in the transmission line. In Figure 3, if $R_L = R_s$ then V_{L1} is half of V_s. If you add a filter between the generator and the load at position X-X, then any additional loss is the result of the insertion loss of the filter.

For the band-pass filter development of this article I used the *Genesys 2010* software from Agilent. I chose the band-pass filter "Top C Coupled" and Chebyshev type, of order 4 and with 5 MHz of bandwidth. After the first tests, it became clear that there was a downshift of the frequency range, and so I made some changes in component values to achieve the frequency range of 132 MHz to 148 MHz.

The model "Top C Coupled" filter was chosen to use fewer inductors (where *Q* is critical), and also to come up with a design that uses component values that are available on the market.

Building It

The biggest challenge in building the filter was the size of the digitally tunable capacitors. They are available as a quad flat-pack, no-lead 12-pin package with dimensions of 2 × 2 mm and 0.5 mm pin spacing!

The circuit board design was done in *Kicad* software and the manufacture was made with common characteristics (2-Layer FR4 1.6 mm).

The capacitors used are commonly available, with 5% tolerance, but the ideal would be to use pre-selected NP0 capacitors. The inductors are manufactured by Coilcraft, and have a *Q* of about 40 at 150 MHz. The inductors also offer a certain challenge to be soldered in place on the circuit board. The finished circuit board is shown in Figure 5. Figure 6 is the schematic diagram of the digitally tunable band-pass filter.

Controls

I adapted an Arduino Uno circuit board

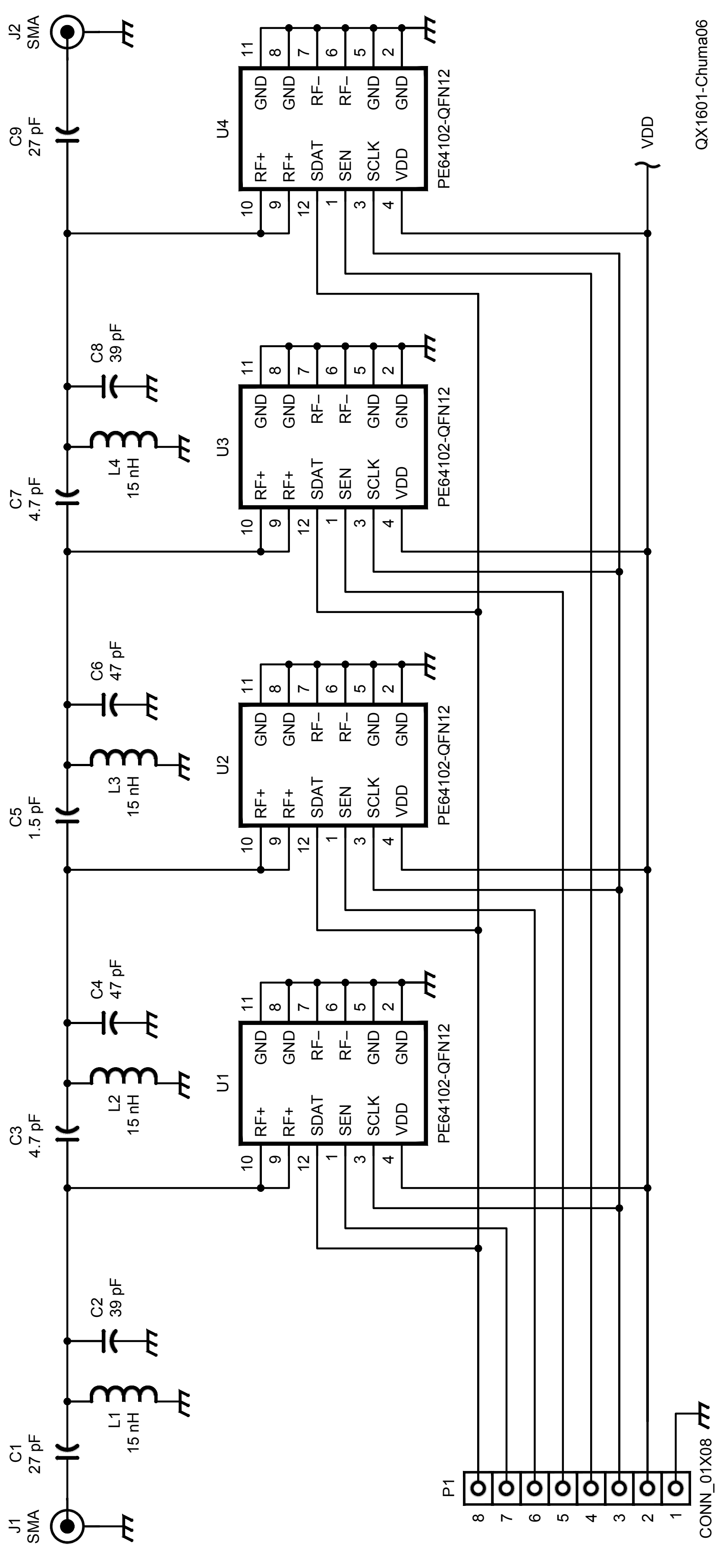


Figure 6 — Here is the schematic diagram of the digitally tunable band-pass filter.

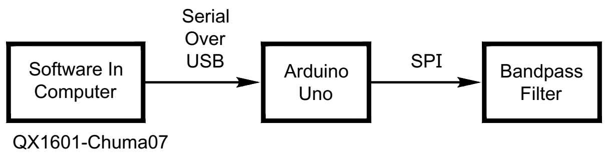
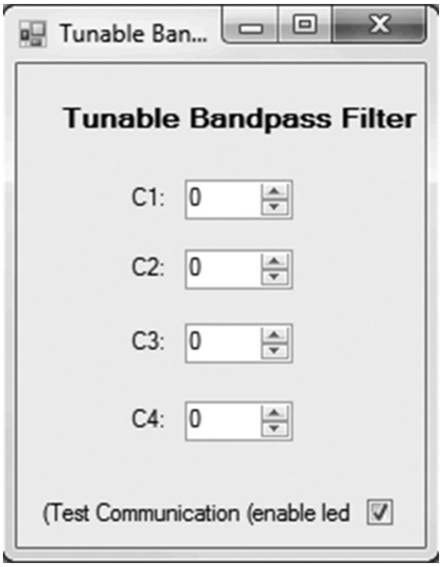


Figure 7 — This block diagram shows the control of the band-pass filter.



Tunable Ban...

Tunable Bandpass Filter

C1: 0

C2: 0

C3: 0

C4: 0

(Test Communication (enable led ☑

Figure 8 — This is a screen shot of the filter control software.

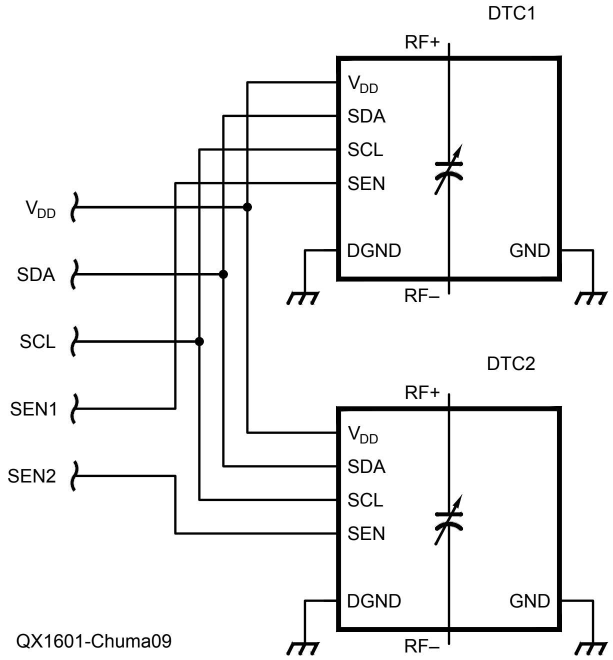


Figure 9 — Here is the serial peripheral interface (SPI) bus sharing to control the digitally tunable capacitors.

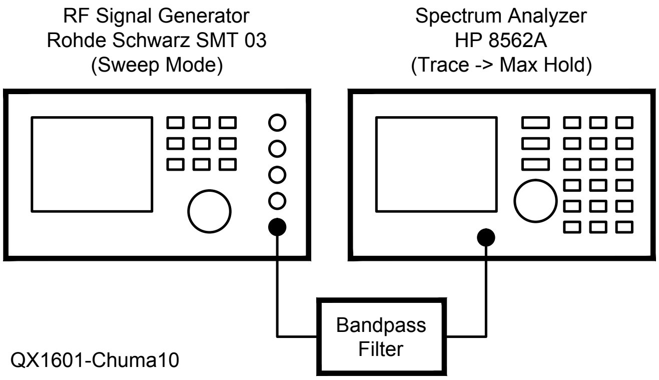


Figure 10 — This diagram shows the test set-up for the filter.

for the control of the digitally tunable capacitors.[2] The Arduino Uno board is controlled by software on a PC that sends commands through a serial-over-USB interface. The lead photo shows the complete set-up, with a laptop computer, the Arduino Uno board and the band-pass filter. Figure 7 is a block diagram of the system.

I adopted this control configuration because it is simple, inexpensive, and allows various filter settings with few hardware changes. The choice of the Arduino Uno was motivated because it is simple to program and has low cost.

The software on the computer was programmed in *C#* with Microsoft *Visual Studio*, using the CmdMessenger library.[3] The software for the Arduino Uno was programmed in Arduino language, which is relatively simple. Figure 8 is a screen shot of the control software for the tunable band-pass filter.

The four PE64102 digitally tunable capacitors use a 3-wire serial 8-bit interface compatible with a serial peripheral interface (SPI) bus, to be controlled by the Arduino Uno board. The digitally tunable capacitor selection is made through the serial enable signal to each capacitor, and then shared on the same bus between all of the capacitors. See the schematic of Figure 9.

The PE64102 digitally tunable capacitors operate with 2.3 V to 3.6 V, and the Arduino Uno board takes 5 V. Thus, I modified the Arduino Uno board to operate with 3.3 V, and thereby the serial peripheral interface bus signals are compatible with these capacitors.[4] There are also other options to convert the serial peripheral interface bus signals of 5 V to 3.3 V.

Results

Although the most appropriate piece of test equipment to adjust the filter would be a vector network analyzer, I did not have one available. Instead, for testing, I used a Rohde & Schwarz SMT 03 RF signal generator with the sweep function enabled and plugged into the filter connector. At the other end was an HP 8562A spectrum analyzer with the "Trace -> Max Hold" function enabled. Figure 10 illustrates these connections.

The results are satisfactory, as can be seen in Figures 11, 12, and 13. For a more detailed analysis a vector network analyzer is needed.

The results point to a downshift of frequency compared to the simulation software. One of the possible causes could be the parasitic capacitance of the circuit board, which was developed with simple software and common materials. Another possible cause is the tolerances of capacitors and inductors. Parasitic capacitances, parasitic resistances, and parasitic inductances of the PE64102

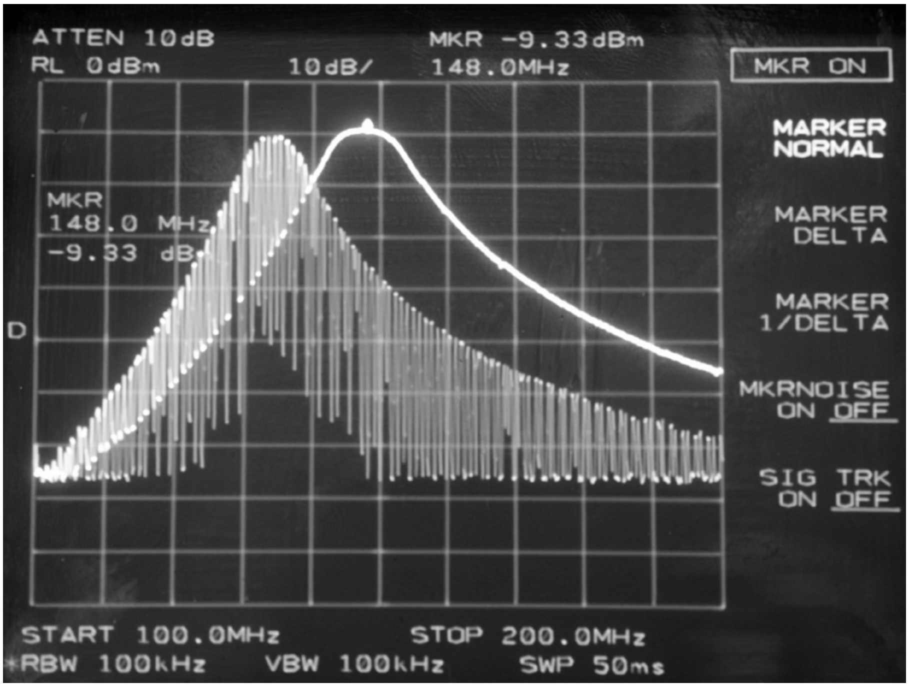


Figure 11 — This spectrum analyzer photo shows the results of the filter test. There are two scans, with center frequencies of 132 MHz and 148 MHz.

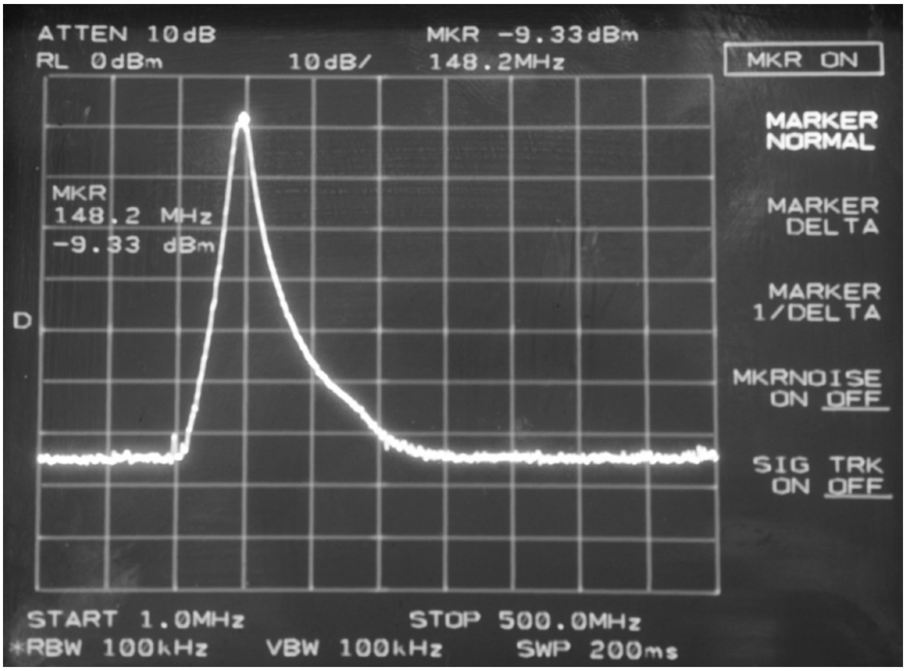


Figure 12 — This spectrum analyzer photo shows a scan of the filter, with the center frequency at 148 MHz.

digitally tunable capacitors may also contribute to this frequency shift. Figure 14 shows a model of the filter circuit, with all of the parasitic components.

Conclusions

The positive points of this project are the linearity of the tuning center frequency, low cost, simplicity and small size. This design is a starting point for more complex projects, such as a set of digitally controlled filters for multiple bands, or even to form part of an SDR design with an adjustable band-pass filter that is controlled digitally by the same SDR software. Then, when the SDR frequency is changed, the software automatically changes the frequency of the band-pass filter.

Euclides Lourenço Chuma, PY2EAJ, earned a degree in mathematics from Unicamp, and a graduate degree in software engineering. Currently, he is working on a graduate degree in network and telecommunications systems in the INATEL. He has been a licensed Amateur Radio operator since 2008, and lives in Brazil. He works in software development, and is interested in everything about RF. He is also interested in antennas, microwaves, SDR and cognitive radio.

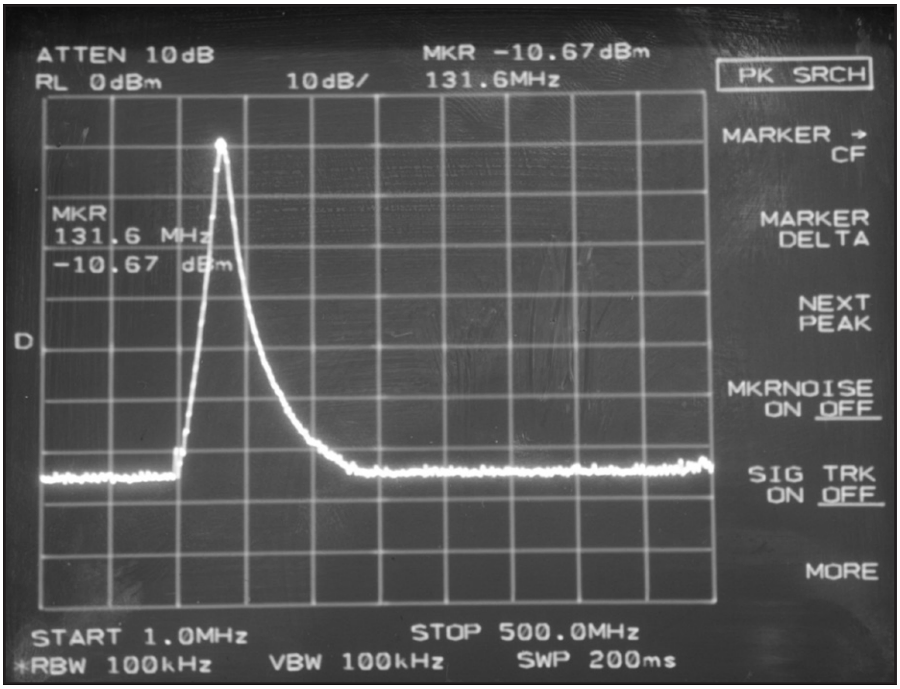


Figure 13 — This spectrum analyzer photo shows a scan of the filter, with the center frequency at 132 MHz.

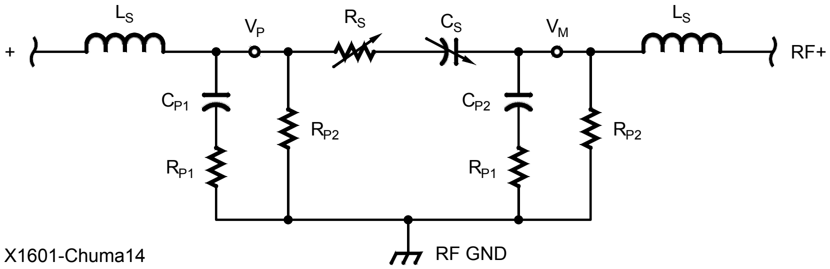


Figure 14 — This is a model of the equivalent circuit of the PE64102 digitally tunable capacitor.

Notes

[1] You can find the Peregrine PE64102 datasheet at: **www.psemi.com/pdf/datasheets/pe64102ds.pdf**.

[2] For details about the Arduino Uno, go to: **arduino.cc/en/main/arduinoBoardUno**

[3] To learn more about the Arduino Uno CmdMessenger and to download the files, go to: **playground.arduino.cc/Code/CmdMessenger**.

[4] Details about converting the Arduino Uno to operate from 3.3 V are available at: https://learn.adafruit.com/arduino-tips-tricks-and-techniques/3-3v-conversion. Software and circuit board files are available at: **www.chumalab.com.br/digitally-tunable-bandpass-filter/**