DEVELOPMENT OF A DIGITAL POTENTIOMETER CIRCUIT FOR DIGITAL COMPENSATION OF FREQUENCY AND TEMPERATURE VARIATIONS OF Kvco TO PROVIDE REPROGRAMMING OF THE TRANSMITTER RF CENTER FREQUENCY IN THE FIELD.

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ABSTRACT

Cobham Electronic Systems, Inc. has developed a digital potentiometer circuit to allow for digital compensation of frequency and temperature variations in the VCO/PLL frequency control loop of a telemetry transmitter. The ability to reprogram the RF center frequency of a telemetry transmitter is a useful feature and is required on many telemetry programs.

When setting the frequency modulation deviation (FM Modulation Index) of a telemetry transmitter, the exact setting will change with RF center frequency due to the variation of the transfer function of the VCO (Kvco). Typically, a resistor divider is used to set the frequency modulation deviation level by setting the output data signal amplitude. However, since Kvco varies with respect to RF center frequency, a method of adjusting frequency modulation deviation for each frequency setting is required. The shunt resistor in the resistor divider is replaced with a digital potentiometer to provide the necessary adjustment, using the on-board microprocessor to store a look-up table of settings versus frequency. A key feature of the digital potentiometer circuit is a method to increase the frequency bandwidth of the potentiometer. Digital potentiometers typically have frequency bandwidths measured in kiloHertz to MegaHertz, which limits their use in setting the frequency modulation deviation of high data rate telemetry transmitters.

The circuit consists of a 256 position digital potentiometer and several resistors that are used to adjust the slope of the resistance vs. digital code curve and to translate the curve up and down along the Y-Axis. Adding external resistors to the digital potentiometer helps to increase the frequency bandwidth of the digital potentiometer. The selection of the maximum resistance range of the digital potentiometer is also important, as the potentiometer bandwidth is greater when a small portion of the total resistance is used. This paper will explore various methods of

increasing the effective bandwidth of a digital potentiometer, with the goal of making them suitable for use in dynamically setting the frequency modulation deviation via digital control.

KEY WORDS

Transmitter, Frequency Modulation Deviation, Digital Potentiometer, Increased Bandwidth

INTRODUCTION

COBHAM has produced a set of rugged, small, low cost transmitter modules for use in telemetry applications. These transmitters utilize direct frequency modulation, which results in a miniaturized system. These transmitters are compliant with IRIG 106-09, using PCM-FM modulation, and can provide an output power level of up to 1 watt. Some are stand-alone transmitters, and others combine a digital encoder and regulated power on a single integrated printed wiring board. These single-card telemetry units provide 1 Watt of transmitted power, with a digital encoder capable of 1 Mbps data-rate in a compact, rugged design that can survive setback accelerations of 15 kG, at temperature extremes of -40°C to +85°C.

Cobham has built upon this foundational telemetry technology to develop a telemetry transmitter that has a maximum output power of 25 Watts, including high data rates up to 10 Mbps, the ability to receive digital commands from a host computer to set transmitter power, frequency and data rate, and a re-programming feature to allow the transmitter firmware to be changed to provide flexibility. The ability to change frequency imposes limitations on the modulation circuitry, as the variations in the transfer gain of the VCO, measured in MHz/Volt, varies with respect to the selected RF transmit frequency. This issue is illustrated in a block diagram shown in Figure 1.

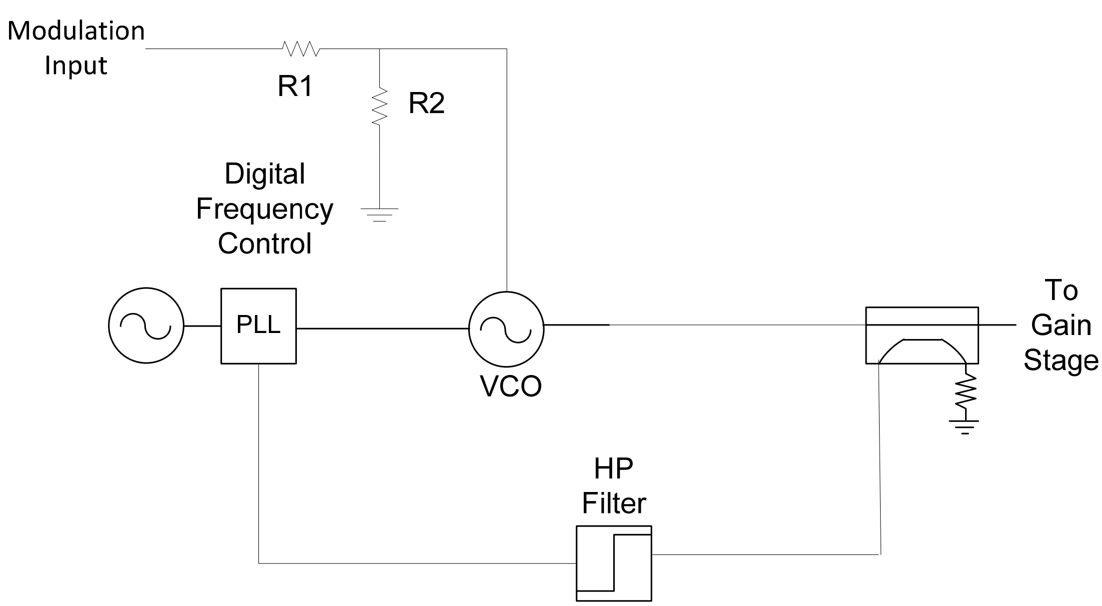

Figure 1 – PLL/VCO Block Diagram

To set up the modulation for a PCM-FM transmitter system, the modulation deviation frequency must be set to 0.35 times the input data rate. The modulation input is digital serial data that has a low logic level of zero, and a high voltage level of 3.0 to 3.3V. The VCO will typically have a transfer gain (Kvco) of 40 MHz/Volt or higher, which would result in a modulation deviation frequency of 120 MHz. For a 10 Mbps data rate, the desired modulation deviation frequency is 3.5 MHz. Therefore the amplitude of the data needs to be reduced, and this is accomplished with the voltage divider created by R1 and R2. For a programmable frequency system, with Kvco changing with respect to frequency, this divider needs to also be variable. A digital potentiometer would be an obvious choice to replace the resistor divider

DISCUSSION

Figure 2 shows a block diagram of the PLL/VCO circuit with a digital potentiometer in place of R2.

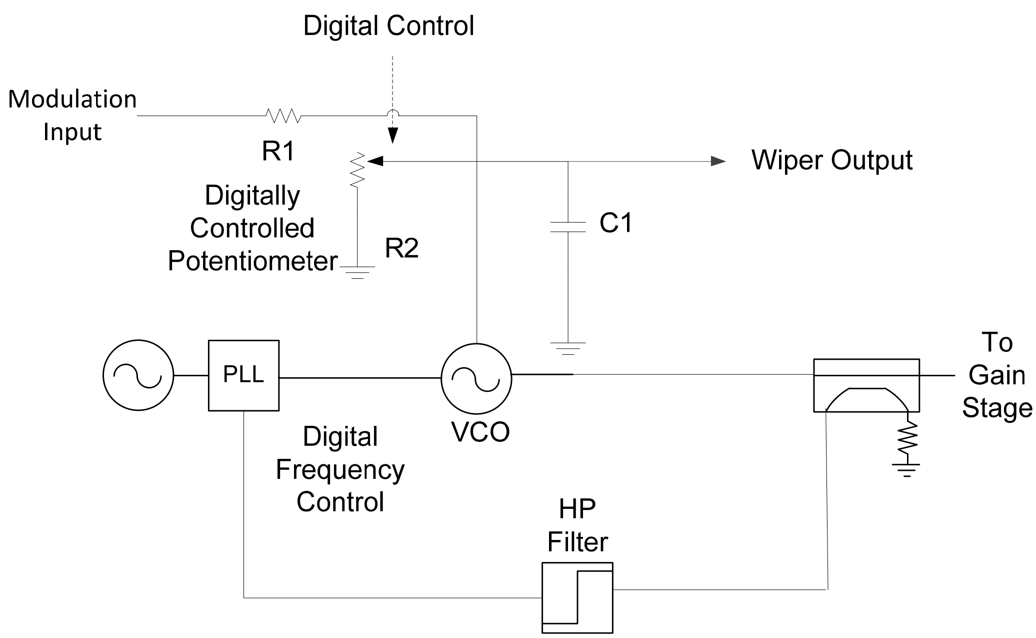

Figure 2 – PLL/VCO Block Diagram with Digital Potentiometer

Please note the addition of C1, which is the wiper capacitance of the digital potentiometer. This is the component that limits the bandwidth of the device. There are also capacitances at each end of the resistor element of the potentiometer (40pF), but the effect of these capacitances is negligible. A digital potentiometer typically defines its bandwidth with the wiper set at the midpoint. In this case we will look at a 2.5K Ohm pot, with R1=R2=1.25K, and C1=160pF. Figure 3 shows the frequency response plot, with the -3dB point at 1.62 MHz.

However, in a typical application, with a 2.5 MHz datarate, the proper attenuation ratio to achieve a modulation deviation frequency of 0.35 times the datarate is 0.01575. This is achieved with R1=10K and R2=160 Ohms. This circuit is shown in Figure 4, and Figure 5 provides the frequency response, with a -3dB point of 5.63 MHz. Even though the total resistance is approximately the same, the -3dB bandwidth is much wider due to the 160 Ohm resistor. The takeaway here is that the bandwidth of the potentiometer is greater when the wiper is near either end of the adjustment range than it is at the midpoint. The value of 160 Ohms is achieved by placing a 220 Ohm resistor (R3) from the wiper pin to ground. This is necessary due to the wiper resistance, which is also 160 Ohms. The potentiometer cannot be adjusted to achieve the required resistance and have any usable adjustment range, so with 220 Ohms in parallel to the wiper, the wiper resistance is set to 591 Ohms to achieve a parallel equivalent of 160 Ohms, which within the usable range of the potentiometer. Please note that for this analysis R4 is unpopulated.

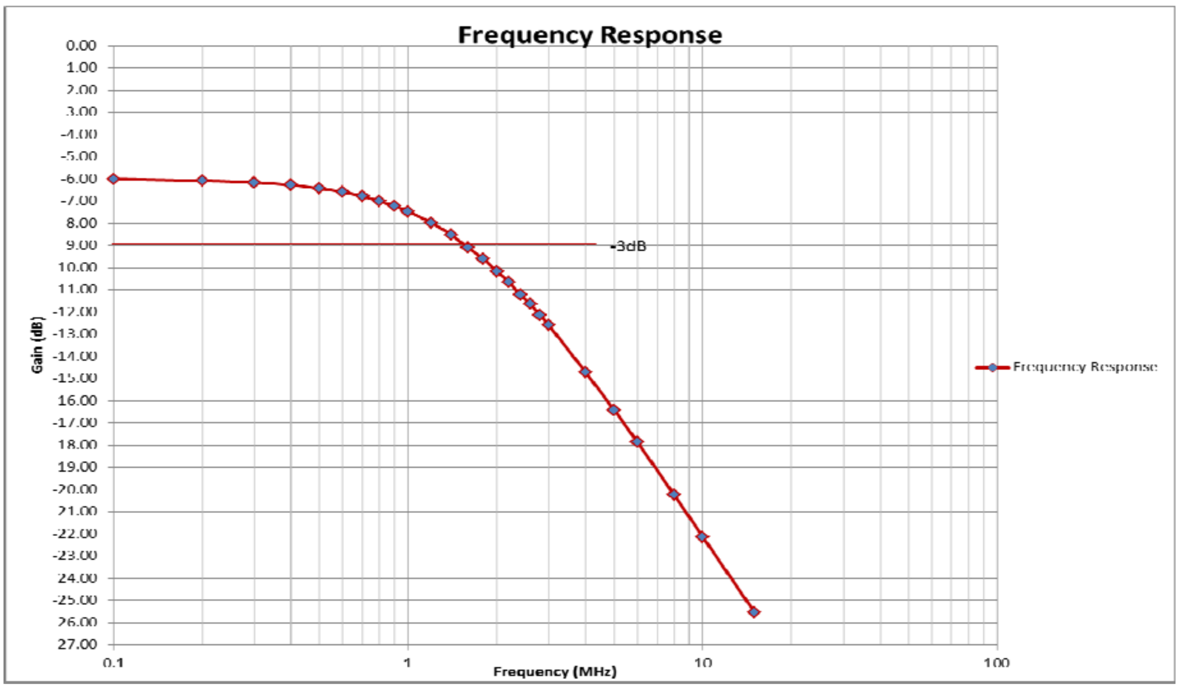

Figure 3 – Frequency Response of Wiper Pin

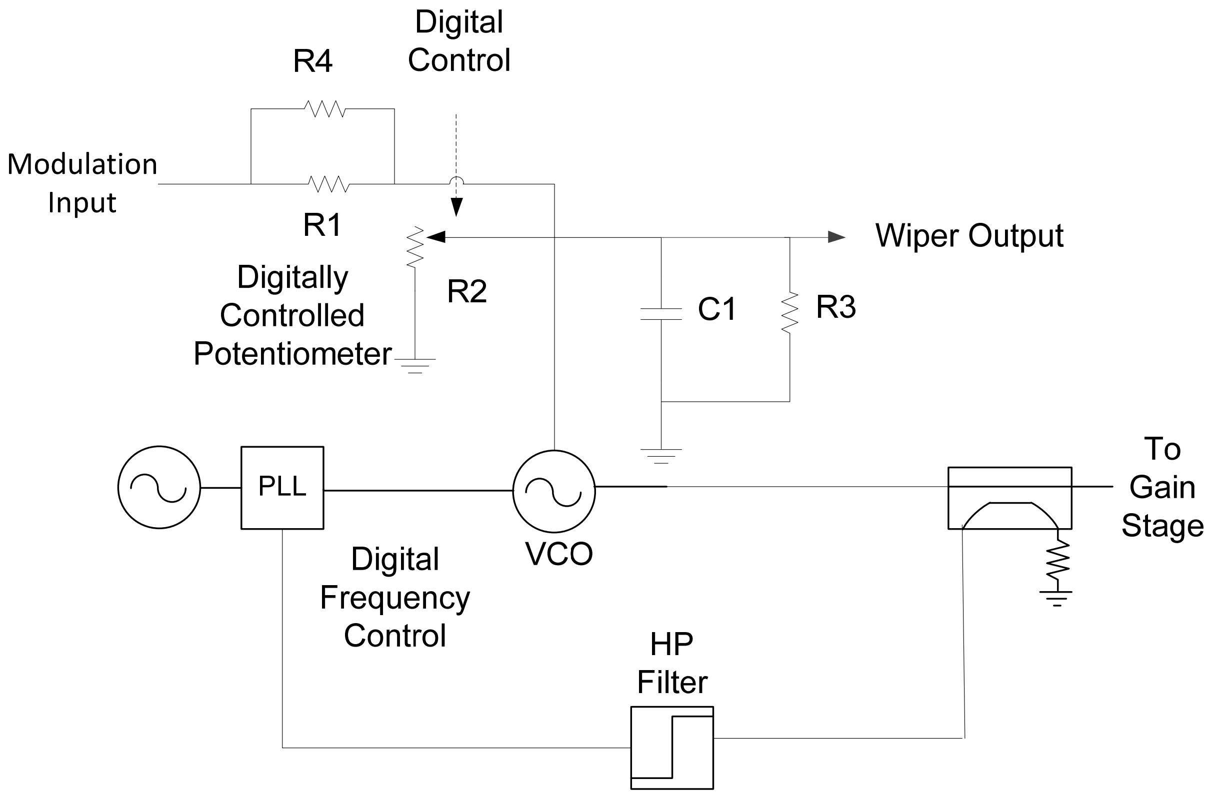

Figure 4 – Potentiometer Circuit with Parallel Resistors

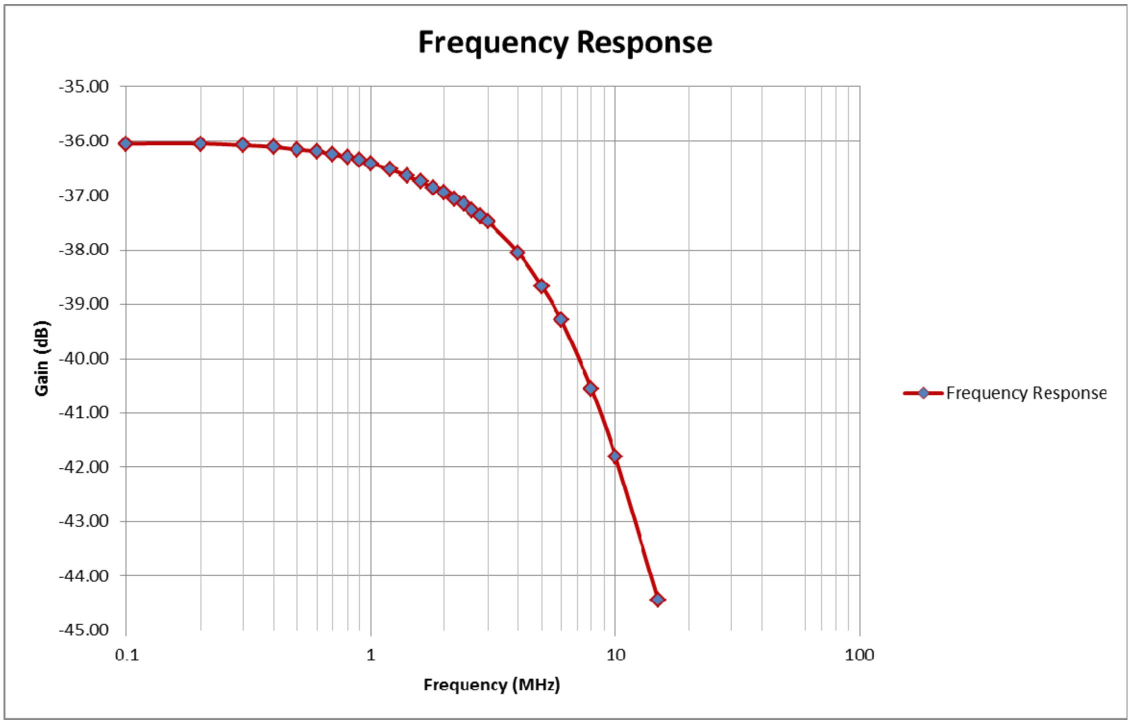

Figure 5 – Frequency Response with R3 = 220 Ohms, and R4 Unpopulated

For applications that require even greater bandwidth, an additional resistor can be added in parallel to R1. In this case we will add a 10K resistor (R4) to create an equivalent resistance of 5K. The value of R3 will be changed to 92 Ohms to create an equivalent resistance of approximately 80 Ohms, which is half of the previous value of 160 Ohms. This is necessary to maintain the desired attenuation ratio. Figure 4 provides a diagram of the new circuit, with R3 = 92 Ohms and R4=10K Ohms, and Figure 6 provides the simulation results.

As can be seen, the bandwidth of the circuit is 12.7 MHz, which is a bit more than double what it was in the previous example. However, there is a price to pay for the extra bandwidth. The effective tuning range of the potentiometer is reduced accordingly. For the circuit of Figure 4 with just R3 = 220 Ohms added, the effective tuning range is 92.6 Ohms to 203 Ohms, but when R4 = 10K Ohms is added, and R3 = 92 Ohms, the effective tuning range is reduced to a range of 58.4 Ohms to 88.9 Ohms. So the need for a specific tuning range and the need for a particular frequency bandwidth have to be traded off against each other. To provide options, one can look for specific digital potentiometers that have a lower wiper capacitance. There are digital potentiometers available that have wiper capacitances as low as 10 pF, but with a potentiometer resistance of 50k Ohms. The use of parallel resistors can reduce the effective resistance, and increase the effective bandwidth, to get the specific resistance required, and take advantage of the much lower capacitance to realize a workable design.

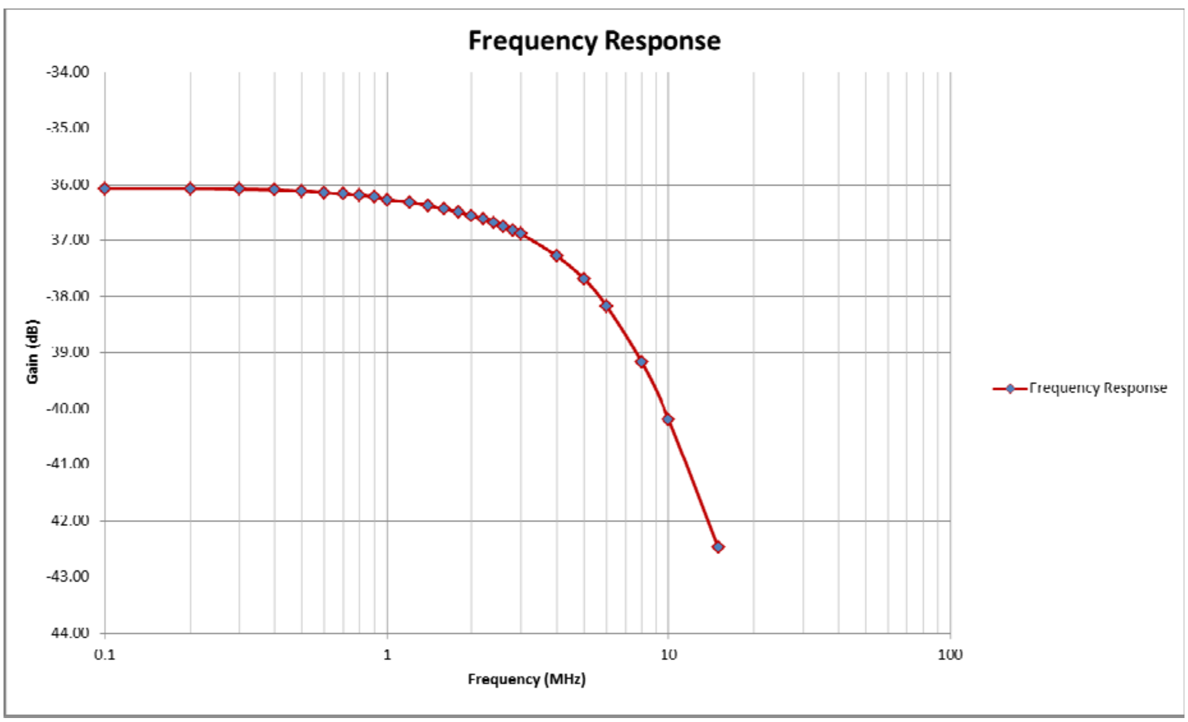

Figure 6 – Frequency Response with R3=92 Ohms, R4=10K Ohms

TEST DATA

The digital potentiometer used for these tests was an Analog Devices AD5162, with a total potentiometer resistance of 2.5K, and an advertised wiper capacitance of 60 pF. However, this is a typical value, and is not the guaranteed maximum capacitance. The circuit diagram of Figure 2 was used to take the frequency response data, which is shown in Figure 7. The potentiometer was set to its midpoint, and the frequency response was measured, resulting in a -3 dB bandwidth of 1.59 MHz. The capacitance in the simulation model was then adjusted to match this performance, which resulted in C1 = 160 pF. This value of C1 was used for the simulation data in Figure 3 , and suggests that there is stray capacitance being added by the evaluation board, in addition to whatever uncertainty there is in the actual wiper capacitance of the potentiometer. Therefore a wiper capacitance (C1) of 160 pF was used for the simulation data as an estimate of the actual capacitance seen by the potentiometer.

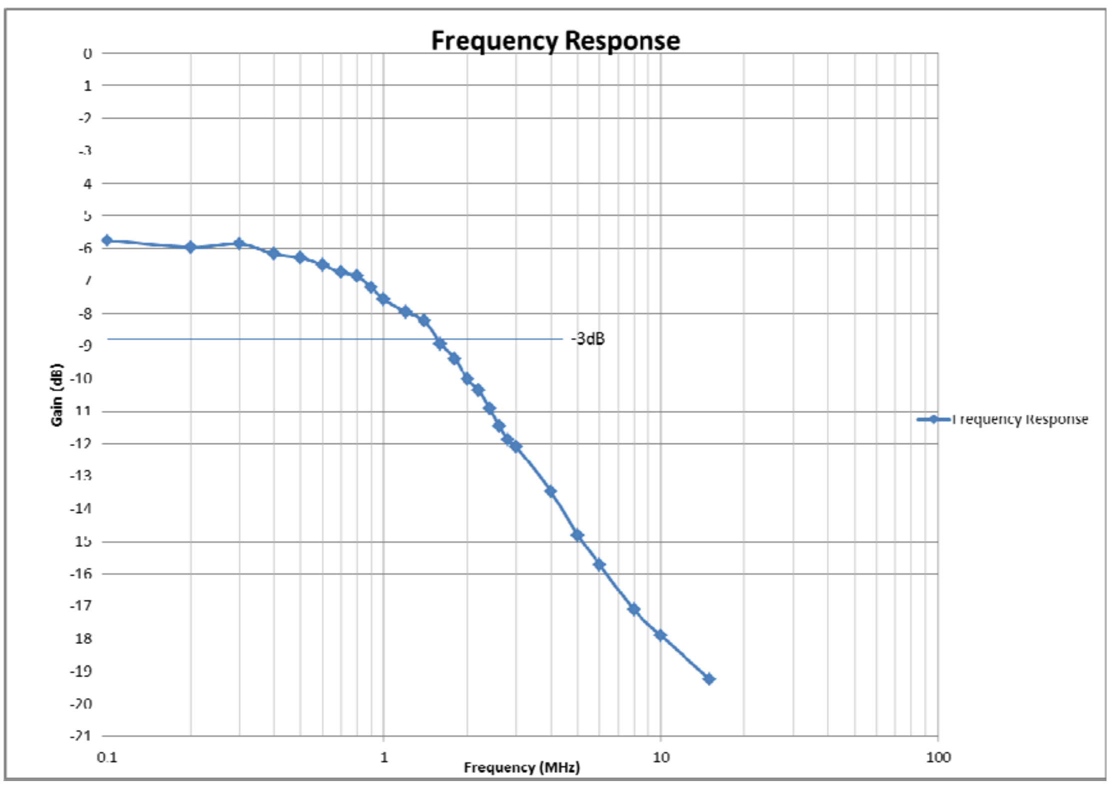

Figure 7 – Measured Frequency Response of the Circuit in Figure 2

The circuit was then altered to the configuration of Figure 4, with R3 = 220 Ohms and R4 unpopulated, and the frequency response was again measured, with a -3dB bandwidth of 3.8 MHz, which is shown in Figure 8. This is a significant increase (more than double) over the 1.59 MHz bandwidth in Figure 7.

The circuit was then altered again to add R4 = 10K Ohms and R3 changed to 92 Ohms, and the frequency response was again measured, resulting in a -3dB bandwidth of 7.8 MHz, as shown in Figure 9. It is lower than the simulated value of 12.7 MHz, but adding parallel resistors clearly shows a bandwidth improvement, again better than double (2.05X).

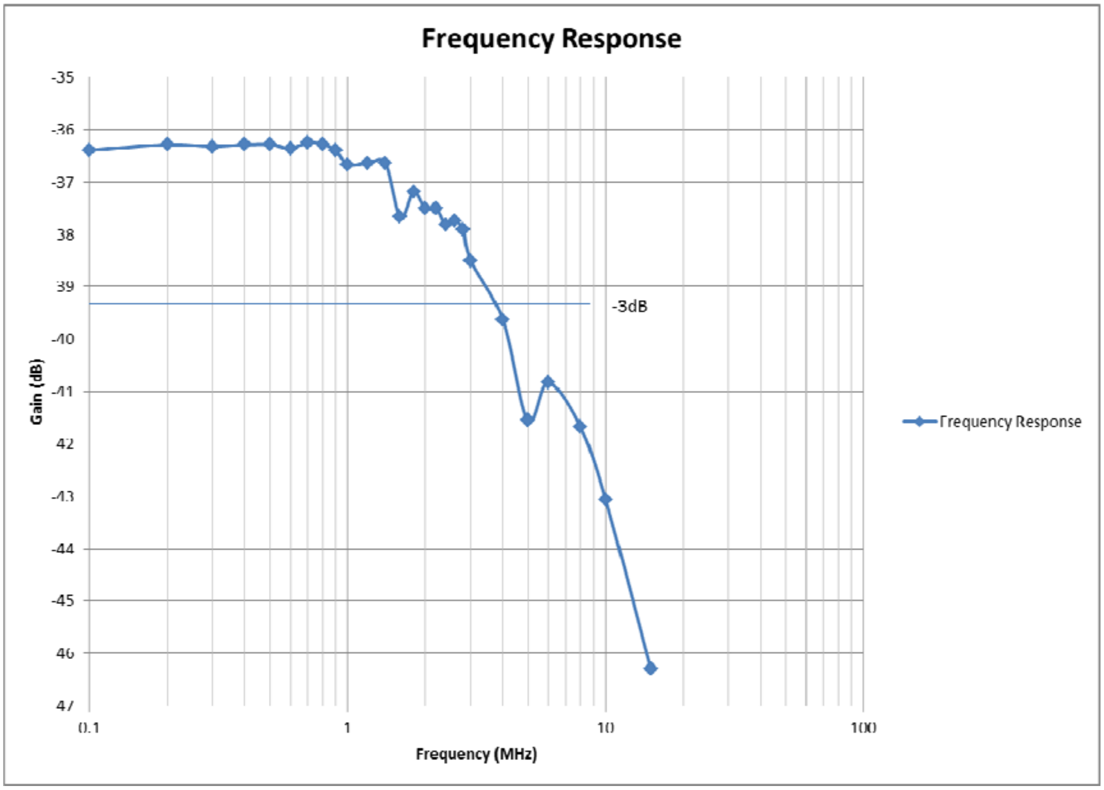

Figure 8 – Measured Frequency Response of the Circuit in Figure 4, with R3 = 220 Ohms, R4 unpopulated

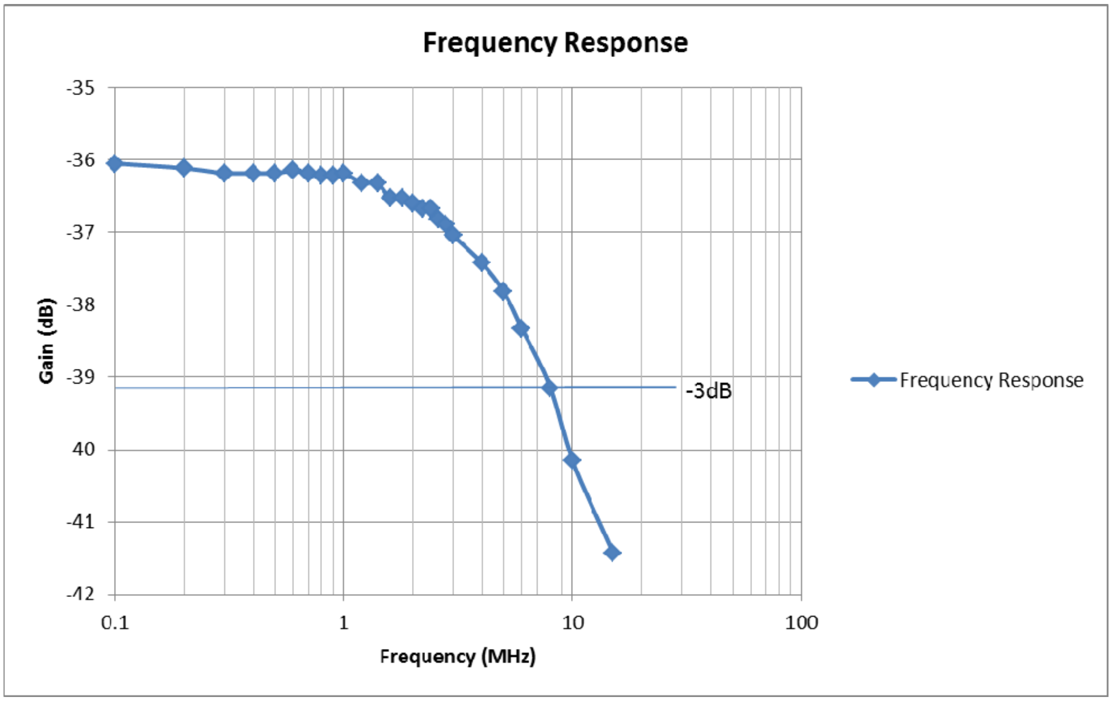

Figure 9 – Measured Frequency Response of the Circuit in Figure 4, with R4 populated with 10K

CONCLUSIONS

Digital potentiometers are very useful in applications where a digitally controlled resistance is needed. Cobham has used them in the past to digitally adjust RF power, but applying it to adjust modulation deviation frequency is a new application. As data rates increase, the frequency bandwidth of the potentiometer becomes an issue, which is limited primarily by the wiper capacitance. Since the bandwidth is determined by the interaction of the potentiometer resistance and the wiper capacitance, and since the capacitance cannot be altered, the obvious solution is to change the resistance by adding other resistors in parallel. As this paper has shown, the frequency bandwidth of a digital potentiometer can be easily improved by 4.9X, and even higher ratios can be achieved through careful component selection. However, there is a price to pay, as the tuning range of the potentiometer decreases when parallel resistors are added. Keeping that in mind, this method of compensating the modulation deviation frequency with respect to variations in the Kvco of the VCO due to changes in RF center frequency can be applied to almost any telemetry transmitter application that needs a digitally variable resistor or resistor divider.

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