Application Report

AFE7070 Optimized Operation in the VHF Band

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ABSTRACT

The AFE7070 is an integrated digital-to-RF conversion device suitable for low power applications operating with 20 MHz of bandwidth or less. It is ideal for compact software-defined radios, pico-cell base stations, or remote communication transmitters. Since the device integrates an analog quadrature modulator, it is susceptible to imbalances on the baseband paths that impair RF performance related to carrier feedthrough and sideband suppression. This application report outlines a procedure to optimize the RF output over frequency and temperature with just three calibration points. The calibration consumes less than 10 seconds of factory test time and the correction algorithm provides robust performance over the desired frequency band and environmental variations.

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1 Introduction

The AFE7070 device integrates a 12-bit, 65-MSPS dual digital-to-analog converter (DAC), baseband low-pass filters, and a quadrature modulator. The AFE7070 is a convenient low power digital-to-RF conversion device suitable for a variety of transmitter applications from 100 MHz to 2.7 GHz. The integrated baseband filters have a bandwidth of 10 MHz which support RF signals bandwidths up to 20 MHz. The DAC incorporates a Numerically Controlled Oscillator (NCO) which moves the complex signal within the 20 MHz RF band window. The DAC also incorporates digital quadrature modulator correction (QMC) to suppress the spurious performance of the modulator.

The integrated quadrature modulator behaves similarly to its discrete counterparts. In an ideal modulator, the carrier (that is, LO) and the image frequency are completely suppressed. In a real modulator, DC offset imbalances within the baseband inputs manifest as carrier feedthrough (CF). Amplitude and phase imbalance in the baseband inputs degrade the sideband suppression (SBS). The QMC correction in the DAC adjusts for the modulator imperfections to suppress those components to the noise floor; however, the corrections only hold for a single frequency point and for a single set of conditions. Once frequency, LO power, or temperature change, the corrections are no longer optimized and the carrier feedthrough and sideband suppression degrades.

It is impractical to calibrate and store optimized QMC values across all frequencies and conditions. The goal is it achieve the best suppression across all conditions with three room-temperature calibrations points: the low, mid, and high frequency within the band of interest. A simple algorithm approach modifies the QMC calibration points based on current operating conditions.

The use case focuses on operation in the VHF band with the following specifications:

- Frequency: 136–174 MHz
- Carrier Feedthrough: < –55 dBm over all use cases
- Sideband Suppression: < –55 dBc over all use cases
- Temperature Range: –40 to 55°C
- Calibration points: 3

Initially it is important to understand the inherent performance of the device within the band of interest with respect to variation of the following parameters:

- Variation over frequency
- Variation over power supply
- Variation over LO power
- Variation over NCO
- Variation over temperature

Although this use case focuses on the VHF band, the techniques and approach are suitable for any band.

2 CF and SBS Characterization

This section describes CF and SBS characterization.

2.1 Variation Over Frequency

The CF and SBS performance are known to vary over frequency. Figure 2-1 and Figure 2-2 show the characterization data of CF and SBS performance over frequency for an unadjusted (that is, uncalibrated) case and the adjusted case where each point is optimized.

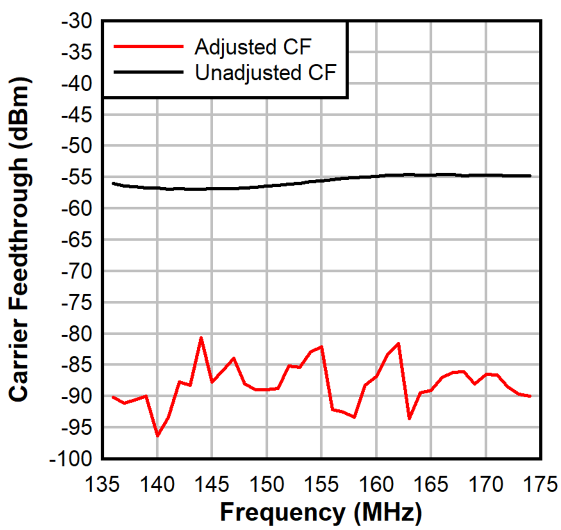

Figure 2-1. Unadjusted CF vs Frequency

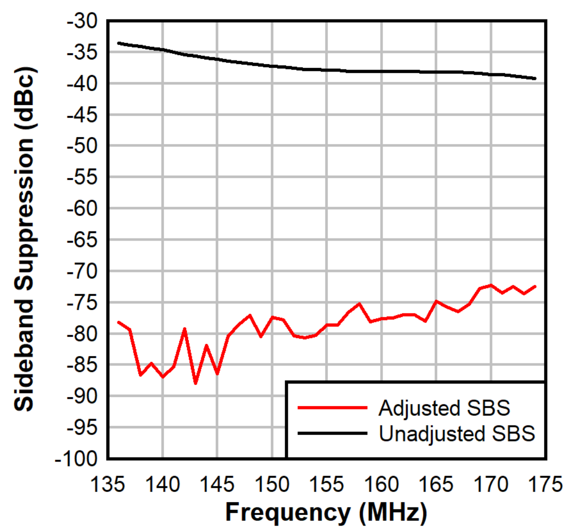

Figure 2-2. Unadjusted SBS vs Frequency

The carrier feedthrough performance at the lower frequencies is inherently good. Unadjusted performance hovers around –55 dBm. With optimization, the CF performance improves to below –80 dBm. Conversely, the sideband suppression starts off at a higher level. This is understandable knowing the polyphase circuit of the device that generates the quadrature signals of the LO is operating at the edge of its designed range. It is expected to have more phase imbalance as the frequency drops. SBS performance is around –40 dBc at the high end of the band and degrades to –33 dBc at the low end of the band.

Figure 2-3 and Figure 2-4 show the optimized QMC parameters across frequency for one device. The absolute value is not important as those values are different for each device. The key observation is the slope and variability of the parameter over frequency; this indicates how well the optimization algorithm interpolates between known calibration points.

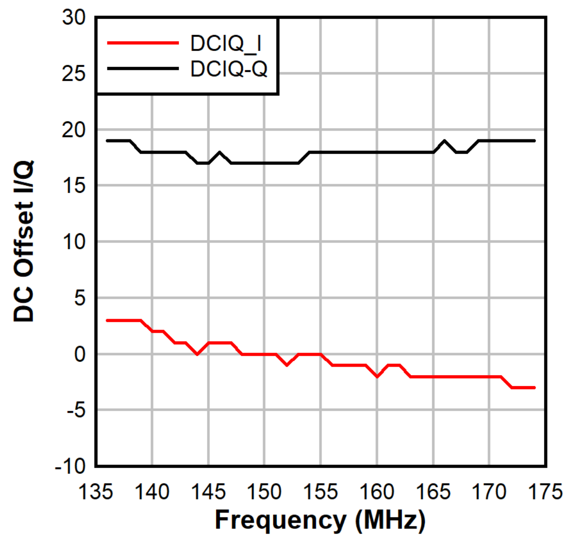

Figure 2-3. DCI/Q vs Frequency

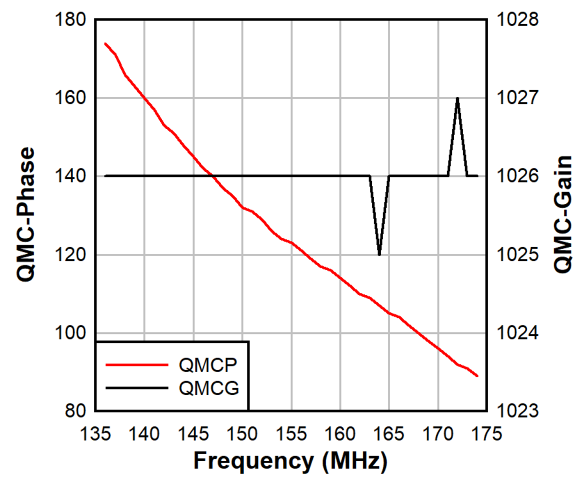

Figure 2-4. QMCP and QMCG vs Frequency

The DCI/Q variation is not excessive. This is anticipated since the CF performance remains fairly consistent. The QMC-Gain is nominally at 1024. For this particular device there is a consistent gain adjustment of 2 steps from nominal with an occasional adjustment by one step higher or lower. The QMC-Phase parameter exhibits the biggest change. Technically, the curve fit of the response is a second-order polynomial, but if the response is broken into two pieces, corresponding to low and high band, each section is approximately linear with a slightly different slope. Using linear interpolation between three frequency points yields a good approximation of the optimized set-point across frequency. Similarly, linearly interpolated values between calibration points is used to determine the intermediate points for the DCI/Q and QMC-Gain. Figure 2-5 and Figure 2-6 show the corrected CF and SBS performance over frequency using just 3 calibrated points.

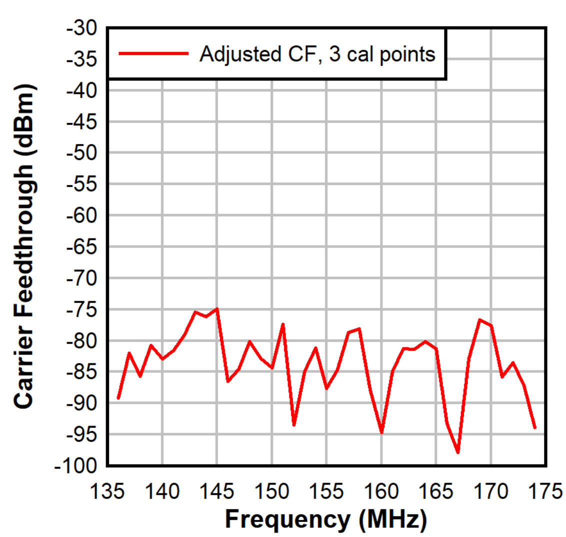

Figure 2-5. Adjusted CF vs Frequency

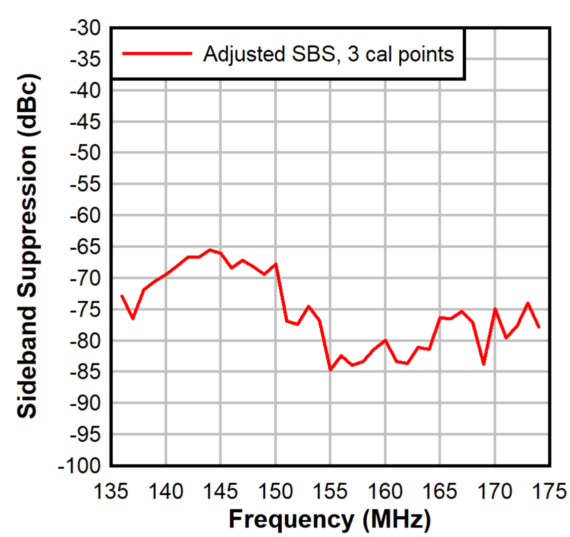

Figure 2-6. Adjusted SBS vs Frequency

2.2 Variation Over Power Supply

Power supply variation has the potential to distort the suppression performance, so it is important to characterize this performance. Characterization data shows that the power supply variation within the data sheet tolerances does not significantly impact CF or SBS performance. This variation is neglected for the suppression analysis.

2.3 Variation Over LO Drive Level

LO drive variation also may distort suppression performance. This parameter does indeed impact performance, especially sideband suppression. The nominal LO drive is 4 dBm. Figure 2-7 and Figure 2-8 show the variation of the CF and SBS performance with respect to drive level varying from 3 to 5 dBm. This is actually a sensitive variable showing that suppression performance degrades 15 to 30 dB from the optimum point with just a ±1 dB drive level variation.

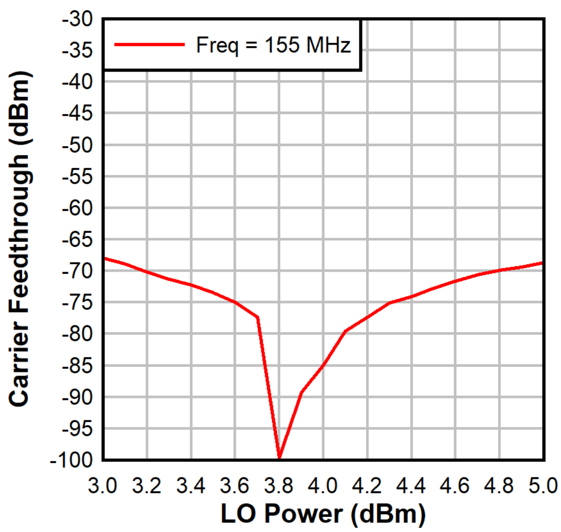

Figure 2-7. CF vs LO Drive

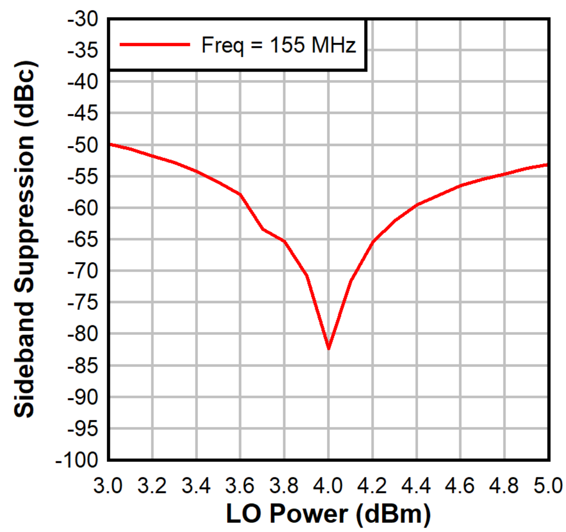

Figure 2-8. SBS vs LO Drive Level

LO drive level sensitivity is particularly burdensome because variations in the LO drive are difficult to predict and measure. The synthesizer device providing the LO signal is subject to its own variation over frequency, power supply, and temperature. It is difficult to accurately predict or measure the LO signal in real time to adjust for any variation over operating conditions. The better approach is to select an LO synthesizer that inherently has little variation in output power for environmental conditions. For the actual product LO, the LMX2572LP synthesizer plus harmonic filter is recommended. The LMX2572 has minimal variation in LO drive strength over temperature and power supply and consumes low power. It is an ideal candidate.

2.4 Variation Over Temperature

CF and SBS vary over temperature. The optimized QMC correction values shift over temperature. For best performance, the system should monitor board or ambient temperature and apply a temperature compensation adjustment to the QMC parameters to maintain best performance. Figure 2-9 and Figure 2-10 show the temperature slope of the QMC parameters. As before, the QMC-Phase has the most variation. In general, the parameter slope is linear with respect to temperature. Table 2-1 lists the temperature slopes across the frequency range.

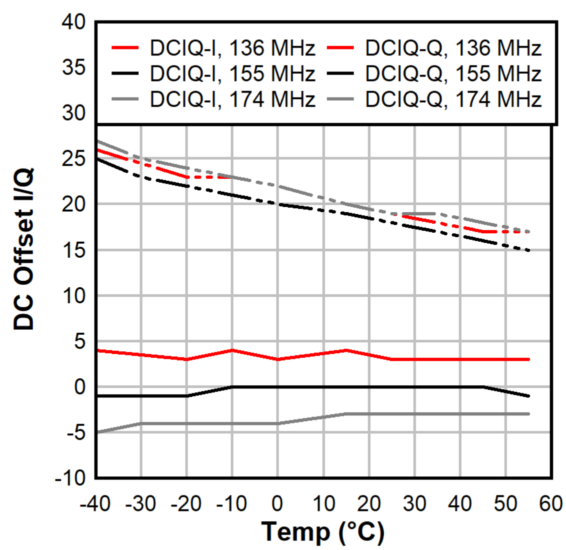

Figure 2-9. DC Offset I/Q vs Temperature

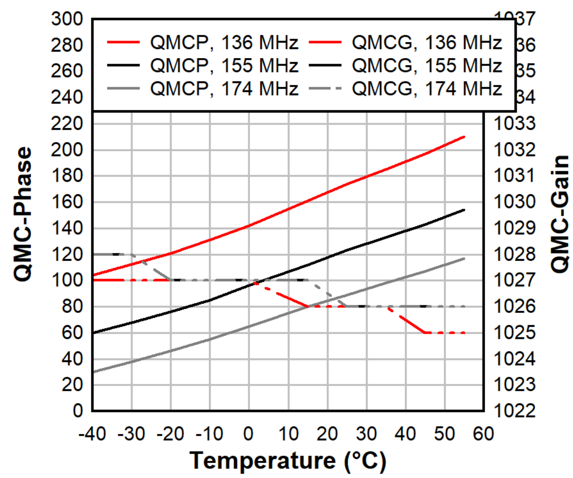

Figure 2-10. QMC vs Temperature

Table 2-1. Temperature Slope vs Frequency

Temperature Slope Parameter	136 MHz	155 MHz	174 MHz
mT_DCI	–0.11	–0.09	–0.10
mT_DCQ	0.07	0.06	0.06
mT_Gain	–0.04	–0.06	–0.08
mT_Phase	1.90	1.62	1.41

2.5 Compensation Algorithm

The compensation algorithm must know the frequency and temperature of operation. The algorithm computes the modified correction parameters in three steps given 3 room-temperature calibration points at the min, mid, and max frequencies in the band. First, the algorithm linearly interpolates between the calibration points to determine the modified correction at the specific frequency of operation. Next, the temperature slope is interpolated across frequency to derive the modified temperature slope at the frequency of operation. Last, the temperature slope is used to adjust the correction parameters for the specific temperature of operation.

2.6 Algorithm Calculations

The algorithm is essentially a series of linearly interpolated values based on the specific calibration points unique to each device and the temperature slopes characterized for the device at specific frequencies. The calibrated points are represented by (x1, y1) and (x2, y2). Note, there are actually three calibrated points, so choose the two points that encompass the actual frequency of operation. Variable *y0* represents the new calibration parameter at frequency *x0*. First, calculate the adjusted value based on the frequency by interpolating between known calibration points.

$$m = \frac{y2 - y1}{x2 - x1}$$

$$y0 = y2 - m(x2 - x0) \tag{1}$$

Next, calculate the temperature slope at the frequency of interest with the characterized slope per frequency as Table 2-1 shows.

$$m_T = \frac{m_{T2} - m_{T1}}{x2 - x1}$$

$$m_{T0} = m_{T2} - m_T(x2 - x0) \tag{2}$$

Finally, apply the temperature slope to derive an updated value at the frequency of interest.

$$y0_T = y0 - m_{T0}(T_{Room} - T_0) \tag{3}$$

Equation 1 through Equation 2 consolidates into the following Python® code. The variable *Fcal* is an array with the calibrated frequency points. The variable *DataCal* is an array with the calibrated values and *mTemp* is the characterized temperature slopes. The *ExtractCalPt* function uses the array information to align with the specified frequency and temperature to calculate the adjusted parameter value.

```
def ExtractCalPt (Fcal, DataCal, mTemp, Freqi, Tempi) :
    FDatai = int(round(np.interp(Freqi, Fcal, DataCal)))        # Frequency adjustment
    mi=np.interp(Freqi, Fcal, mTemp)                            # Temp slope at freq
    FTDatai=int(round(mi*(Tempi - 25) + FDatai))                # Temp Adjustment
    return(FTDatai)
```

As an example, find the *QMCP* parameter at 140 MHz at –20°C given the following calibration points for the device: (136 MHz, 210) and (155 MHz, 157). Applying the calculations or executing the code yields a modified QMC-Phase parameter of 116.

2.7 Composite Results

Figure 2-11 and Figure 2-12 illustrate the composite results using the three calibration points and the algorithm adjustment for variation over frequency and temperature. Carrier feedthrough performance achieves better than –60 dBc and sideband suppression achieves better than –50 dBc across the frequency and temperature range.

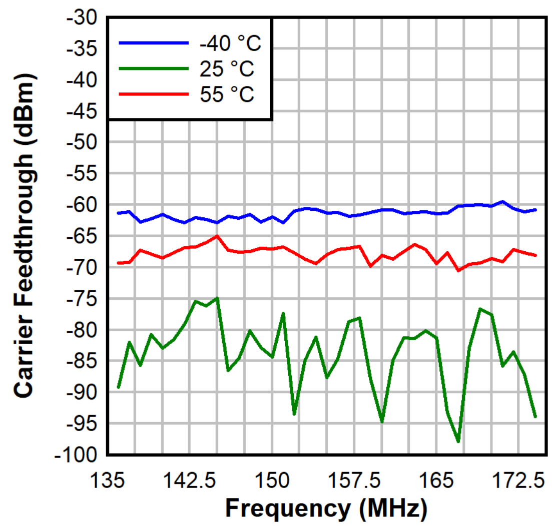

Figure 2-11. CF vs Frequency Over Temperature

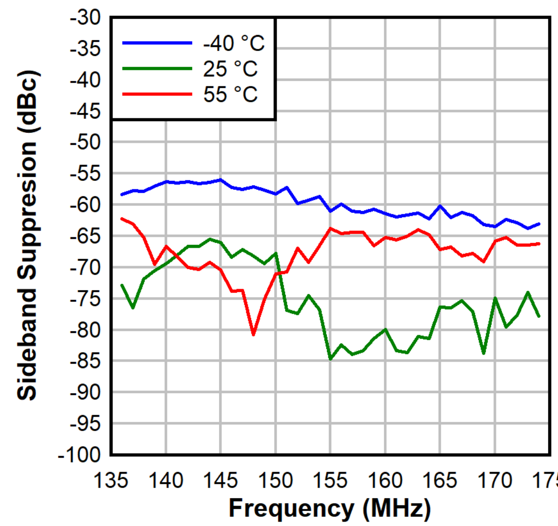

Figure 2-12. SBS vs Frequency Over Temperature

2.8 Mitigate Frequency Variation With the NCO

As previously shown, the modulator correction performance depends on LO frequency. It is possible to use the internal NCO to provide some relief to the frequency tuning requirements. The integrated baseband filters facilitate driving the signal up to ±10 MHz around an LO set-point. In practice, the entire range cannot be used without incurring some amplitude roll off at the edges due to the filters. Generally speaking, the device achieves a flat response up to 80% of the bandwidth. This technique keeps the LO frequency fixed and varies the NCO to move the signal within a 16-MHz window. With three calibrated LO points you can cover almost 50 MHz of tunable bandwidth.

Figure 2-13 and Figure 2-14 compare the corrected CF and SBS performance when shifting the LO versus shifting the NCO. Performance with the NCO shift stays more consistent. In other words, the variation of the baseband signal and a fixed LO is more consistent than the other way around with the baseband fixed and the LO varied.

Using the NCO to shift over frequency offers a unique advantage in that QMC frequency correction is likely not needed. The fixed LO frequencies are calibrated out for best performance. Further, the temperature slope adjustment with respect to frequency is also not needed. This provides an easier, more consistent response without incurring the tolerance error of the frequency control algorithm.

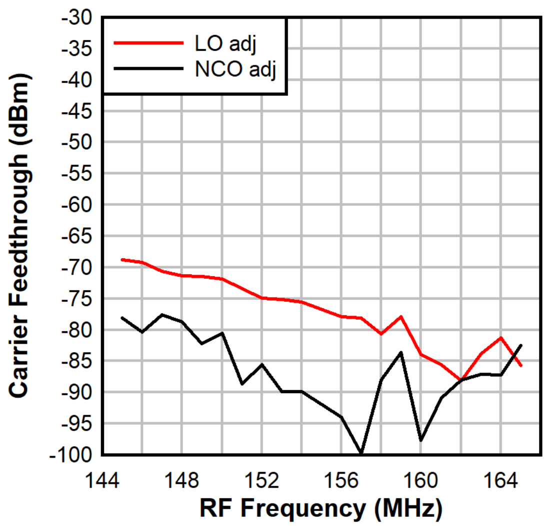

Figure 2-13. CF Over NCO and LO Adjustment

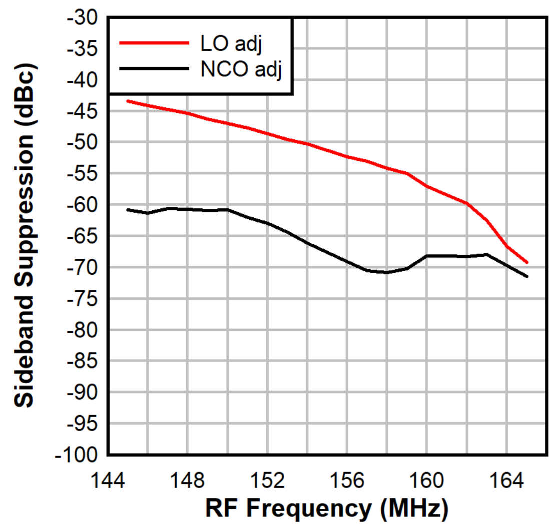

Figure 2-14. SBS Over NCO and LO Adjustment

2.9 Composite Results With the NCO

Using the NCO tuning algorithm, it is possible to cover the RF range from 136 MHz to the 174 MHz in three frequency chunks with about 13 MHz per chunk. The NCO is varied from +6.5 MHz to –5.5 MHz around the LO set-point values of: 141.5 MHz, 153.5 MHz, and 166.5 MHz. No frequency adjustment is required; it is assumed the NCO variation over frequency is negligible. The static temperature slope values from Table 2-2 are applied as needed for temperature, characterized at the new static LO set-points. Figure 2-15 and Figure 2-16 show the composite performance over frequency and over temperature range across the entire band.

Table 2-2. Temperature Slope vs Mid-sub-band Frequencies

Temperature Slope Parameter	141.5 MHz	153.5 MHz	166.5 MHz
mT_DCI	–0.104	–0.091	–0.097
mT_DCQ	0.067	0.06	0.06
mT_Gain	–0.046	–0.059	–0.073
mT_Phase	1.81	1.63	1.481

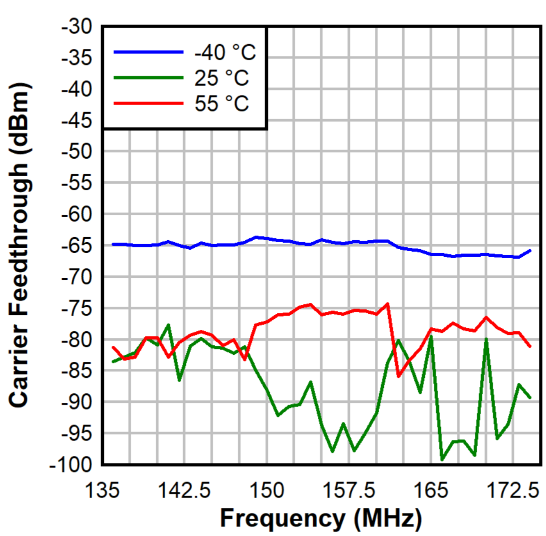

Figure 2-15. CF vs Frequency Over Temperature

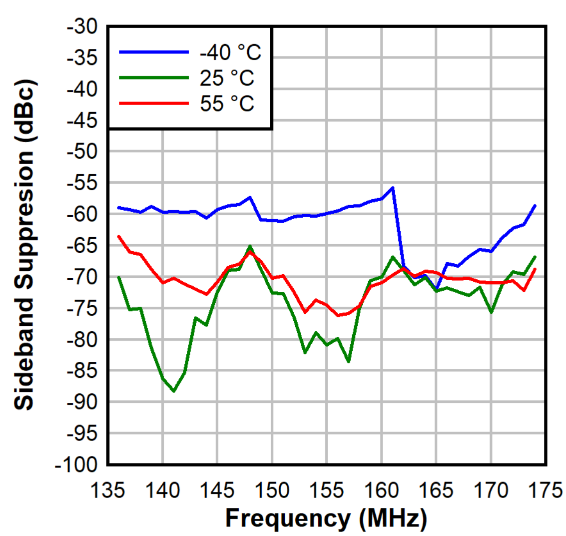

Figure 2-16. SBS vs Frequency Over Temperature

3 Conclusion

With just 3 frequency calibration points, the AFE7070 yields excellent CF and SBS performance across temperature and frequency. The CF performance maintains better than –65 dBm across frequency and temperature. The SBS maintains around –60 dBc across frequency and temperature. Note, the measured performance data utilized the LMX2572LP synthesizer device with harmonic filter for the LO, so the LO variation is built in to the results.

The data outlined here focused on the VHF band, but the technique is applicable to any frequency band within the range of the AFE7070 device. With a different band, a new set of frequency and temperature slope characterization is required. With that data, the same algorithm approach will yield optimized results across the desired frequency range and temperature.