ADDRESSING FREQUENCY DRIFT IN TUNABLE FILTERS

Mehmet Karaaslan

Teledyne Defence Ltd, Airedale House, Acorn Park, Shipley BD17 7SW, UK

ABSTRACT

Narrowband resonant circuits exhibit degradation in performance and frequency shift when component characteristics vary due to environmental effects. When the variation is predictable and repeatable, it can be addressed at the design stage by using electronic calibration methods and mechanical sealing. When the variation occurs unpredictably and especially during operation, sophisticated solutions like built-in-test or auto-correction may be needed to counter. This article presents data on such variation and effects on the performance of an X-band tunable bandstop filter as well as the effectiveness of actions to address the variation.

INTRODUCTION

Narrowband resonant circuits, such as electronically tunable filters, contain components and materials whose electrical characteristics change when they are exposed to environmental effects such as temperature, pressure and moisture. Changes in component characteristics often degrade the filter performance changing return loss and even a shift in frequency. For narrowband filters, very small changes may move the filter centre so far away from the desired frequency that the system cannot operate reliably anymore.

If the undesired behavior is predictable and repeatable, the resulting degradation in performance can be compensated electronically and mechanically. For example, variations due to temperature are “designed-in” by storing tuning-voltage settings in lookup tables to be recalled during operation. Variations due to pressure and moisture can be prevented by hermetic housings. ESS methods like burn-in and temperature cycling eliminate defective parts as well as stabilising the component behavior.

If the undesired behavior is unpredictable or unrepeatable, compensation becomes a major challenge, where it can be even more complicated than the design at times. If the degradation occurs in operation, the situation is even worse, as detection and measurement may not be possible. In-service drift could result in undetectable system degradation or even system failure with consequential impact on safety and cost.

NOTCH FILTER

An X-band, tunable narrowband bandstop filter (notch filter) was designed at Filtronic Components (now Teledyne Defence) more than a decade ago. The filter is tuned in 16 MHz steps within X-band from 8.5 to 11.5 GHz. It provides 25dB attenuation in a 40 MHz bandwidth. The notch centre has a typical loss of 60dBc across all temperatures. It operates on a predefined set of centre frequencies. The filter is also termed as fast tuned notch filter due to settling within ± 5 MHz of a designated frequency within 250 ns.

A wide span response of the filter tuned to 8.5GHz is shown in Figure 1.

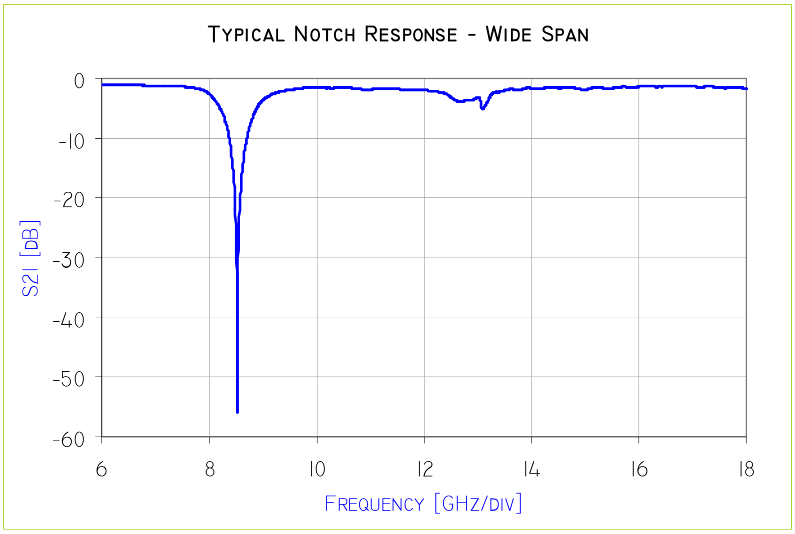

Figure 1. X-band notch filter tuned to 8.5GHz

TEMPERATURE VARIATION

A vast literature and modern modeling tools are available to model individual component variation and simulate the effect on the overall circuit response. The intention of this paper is to look at the end results of such variation and how it is addressed.

The graph in Figure 2 shows the shift in notch centre frequency vs temperature. The horizontal axis shows the tuning frequency range along which each data point corresponds to a different notch tuning. The vertical axis shows the deviation of the notch centre from the alignment frequency. In this exercise, the filter was tuned at temperature band 3 (23°C). The unit was then exposed to temperatures changing from 0°C to +45°C, which are divided into 7 temperature bands. The notch filter shape is retained while temperature varies, however the frequency shifts up to 6 MHz in each direction.

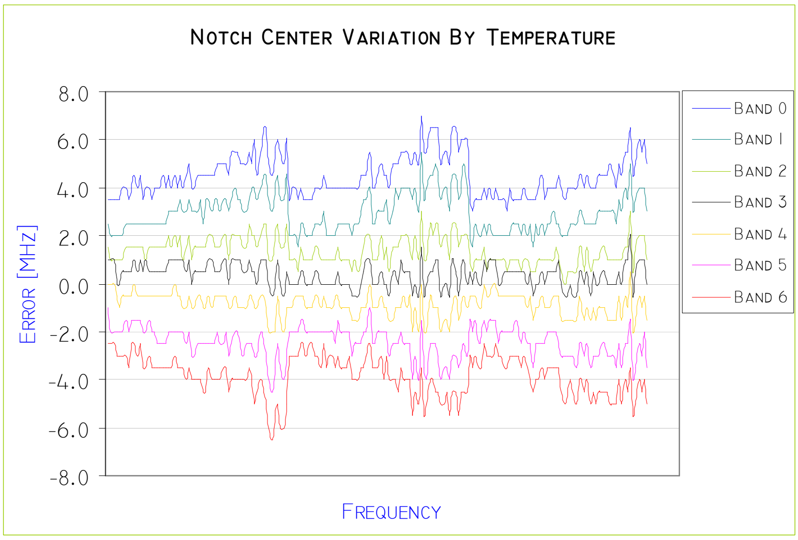

Figure 2. Notch centre variation by temperature

The frequency shift can be corrected by using look up tables for each temperature. Varactor voltage tables are stored electronically within the unit during the alignment and they are recalled during operation by sensing the unit temperature. Creating lookup tables involves more alignment and testing time, but it guarantees better performance than analogue correction methods.

OTHER ENVIRONMENTAL FACTORS

Environmental factors like moisture, pressure, and in combination with temperature also affect electrical performance. Moisture content of the substrate and the air inside the unit changes the effective dielectric constant of the transmission medium. For wideband circuits, this may not be an issue. For narrowband circuits, however, it is a crucial factor.

Figure 3 shows the change in resonance frequency of a distributed element circuit when the dielectric constant changes. A mere 0.1% change in dielectric constant corresponds to a 5 MHz shift at X-band.

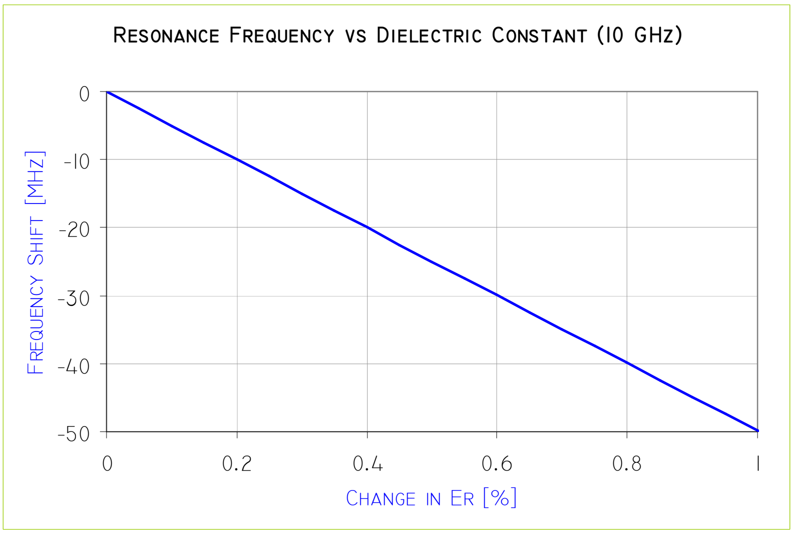

Figure 3. Change in Resonance Frequency

Unless the device is thoroughly baked to remove residual moisture, the frequency of notch centres drifts could drift 5 MHz in a short period, which takes the unit out of specification. Figure 4 shows a typical notch setting when it drifts away 5 MHz.

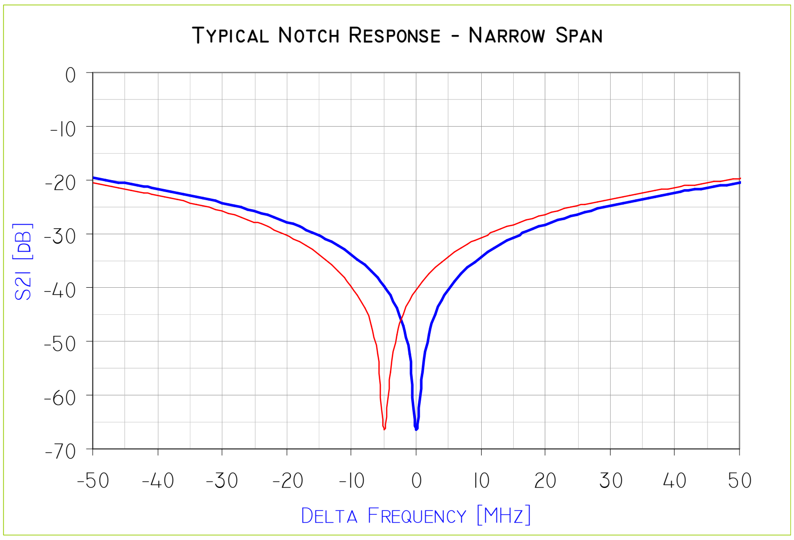

Figure 4. A notch setting compared with 5 MHz drift

An accelerated aging test was carried out to demonstrate the performance of the unit over 20 years. This was based on Peck Hallberg model [1] using temperature and humidity. Figure 5 shows the results with a drift of 3 MHz.

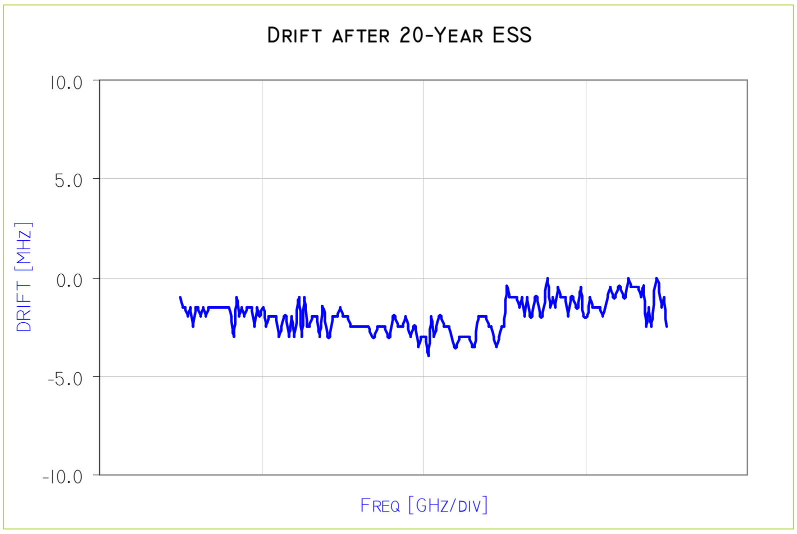

Figure 5. Frequency Drift in Laser Welded Enclosure

This showed that the notches can potentially drift out of specification. In order to combat a possible drift, some options were considered. A routine maintenance such as returning the filter to the factory is one option although that is very costly. Another option, which is cost-effective, is to add a built-in-test circuit, which can correct the drift in-situ.

BITE CIRCUIT

Figure 6 shows the block diagram of the built in test circuit. Its purpose is to generate signals at one end of the notch filter and detect at the other end to provide an insight into the notch position and shape. It is also called an auto-correction circuit, because the findings are used to select the best notch settings.

The notch filter in the middle contains the RF hybrid circuits.

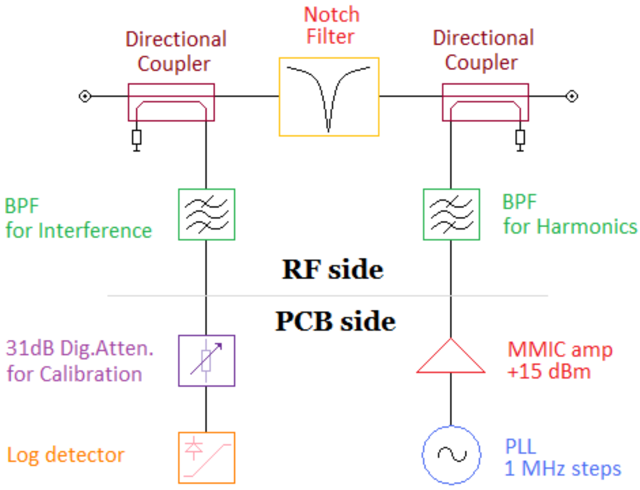

Figure 6. Auto-correction circuit (BITE)

BITE consists of the following:

- PLL with 1 MHz tuning steps. It uses an onboard reference oscillator as phase noise is not a crucial factor.
- MMIC amplifier providing +15dBm minimum output power.
- BPF to filter out harmonics of the PLL. The notch filter may reject the fundamental, but harmonics pass through which causes the detector to read false levels.

- Directional couplers to couple test signal from PLL to detector side. An alternative is to use RF switches, but this compromises sensitivity due to high IL.
- BPF to remove external out-of-band interference signals
- A digital attenuator for calibrating detector power.
- A high performance log detector.

TEST METHOD

There are various methods that the BITE can determine the frequency drift. For example, BITE can be used like a scalar analyzer: PLL frequency can be swept and based on the minimum detection on the log detector end, the notch centre can be located. However, the log detector has a limited sensitivity hence notch depth variations below -50dBc can't be resolved accurately.

The following method works around the sensitivity issue by detecting power at lower attenuation levels. Rather than sweeping the PLL frequency, the method uses fixed frequencies and sweeps predefined notch settings. As the filter settles in 250ns, the speed is not an issue.

In this method, two source frequencies (F_1 and F_2) are selected at an equidistance around a centre frequency, F_C, of the notch to be corrected. Here F_1 and F_2 are assumed to have the same attenuation. First, F_1 is applied to PLL. The notch is swept across the source as shown in Figure 7 and the log detector records the detected RF power. The sweep is repeated with frequency F_2.

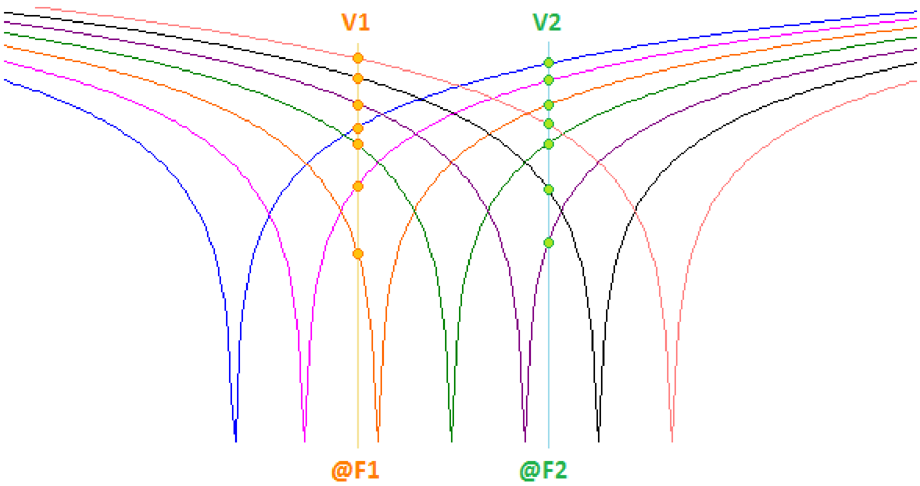

Figure 7. Auto Correction Method

Recordings are designated as V_1 and V_2 as shown in Figure 8a. The difference (V_2-V_1) is called the error term (Figure 8b). When the error term is plotted for each pair of stimuli, it is seen that the notch that gives similar attenuations at F_1 and F_2 is centered nearest to F_C.

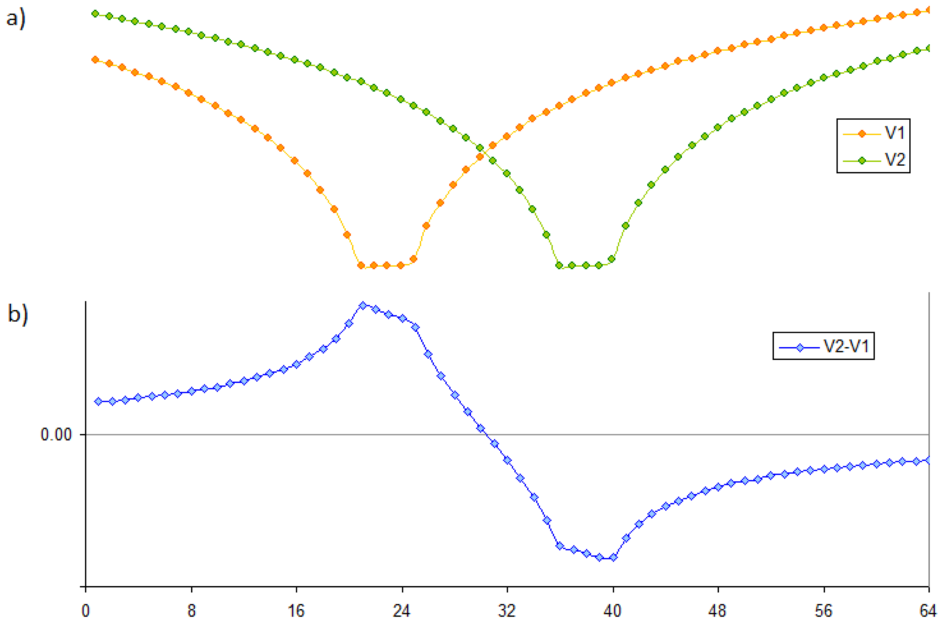

Figure 8. Detector voltages compared

NOTCH SYMMETRY

The method described in the previous section assumes perfect notch symmetry whereas in practice, notch filter stopbands are not symmetric around centre frequency F_C as in Figure 9. The slopes are similar near the centre but one side always skews more than the other towards the passband edges.

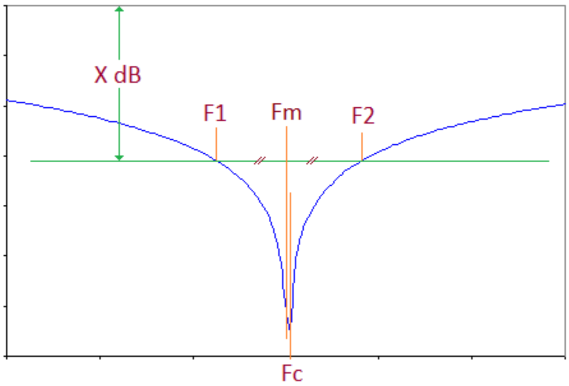

Figure 9. Definitions used in the symmetry study

A study was performed to determine the test frequency step size. The error in the actual notch centre frequency F_C was determined in comparison with the mean, $F_m = (F_1+F_2)/2$.

Figure 10 shows that for stopband depths > 25dB, the error in F_C-F_m comparison is < 1 MHz. For the notch filter of concern, 25dB attenuation corresponds to 40 MHz bandwidth. Therefore F_1 and F_2 are selected 40 MHz apart, i.e., 20 MHz away from the intended centre frequency.

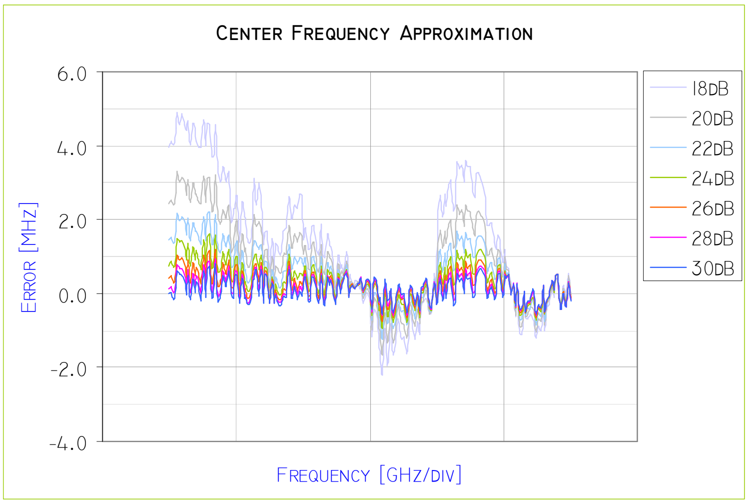

Figure 10. Frequency estimation error

RESULTS OF AUTO -CORRECTION

A filter unit was fully aligned manually and measured with a VNA to accurately determine F_C. The blue trace in Figure 11 shows the deviations from the specified notch centre frequencies. The filter was completely detuned and realigned using the auto-correction algorithm embedded in the firmware. The filter was then retested and the results of the measurement after auto-correction are plotted in orange color. Measurements agree within 2 MHz and they are well within a ± 5 MHz specification.

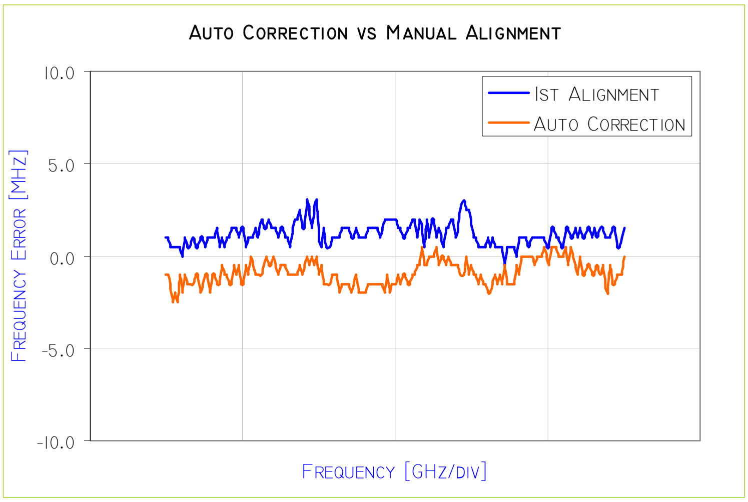

Figure 11. Comparison of Auto-correction Results with Manual Alignment

CONCLUSION

Built-in-test circuits may be used to detect and correct long-term frequency drifts adversely affecting system performance, minimising cost and risk. The auto-correction technique presented in this paper has been successfully implemented to address the potential for frequency drift in an X-band electronically tunable filter thus maintaining the performance of the high accuracy wideband product. The technique can be applied to systems where a drift is observed and one time calibration is not sufficient.

REFERENCES

1. O.Hallberg and D.S.Peck, "*Recent Humidity Accelerations, A Base for Testing Standards*", Quality and Reliability Engineering International, vol 7, pp 169-180 (1991)