Application Note

Anritsu envision : ensure

Automotive Radar Testing with Anritsu's Spectrum Master™ MS2760A Ultraportable Spectrum Analyzer

Introduction

Frequency modulated continuous wave (FMCW) signals are a common form of modulated waveform used in radar applications for object detection. The most common modern-day application is automotive radar, where FMCW chirps may be transmitted in almost every direction for features like adaptive cruise control, blind spot monitoring, reverse warnings, and collision prevention (Figure 1). This application note will review FMCW signal basics, discuss measurement challenges/solutions, and show how the Spectrum Master MS2760A Ultraportable Spectrum Analyzer can conduct basic FMCW radar testing.

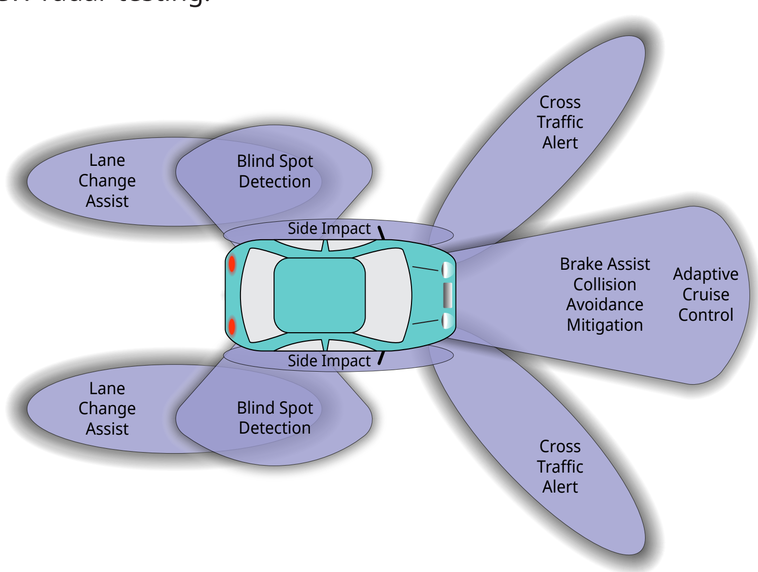
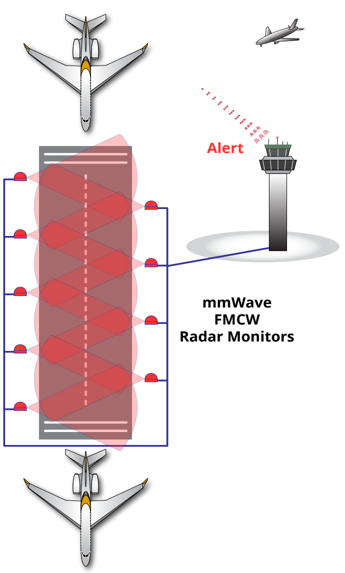


Figure 1: Radar sensors are being used for a variety of different detections in modern automobiles

Real-World FMCW Applications

Another example of FMCW radar in a real-world application is runway monitoring. Radar transmitters are being deployed at airports all over the world to monitor runways for obstacles or debris that might pose a danger to arriving and departing aircraft.



FMCW Chirp Characteristics
A typical linear FMCW signal is a simple sine wave (or CW) signal that is linearly increased in frequency over time. The period of time from when the signal goes from the lowest to highest frequency is called a chirp. This can be represented as amplitude over time, like in Figure 2, or more commonly as frequency over time, as shown in Figure 3.

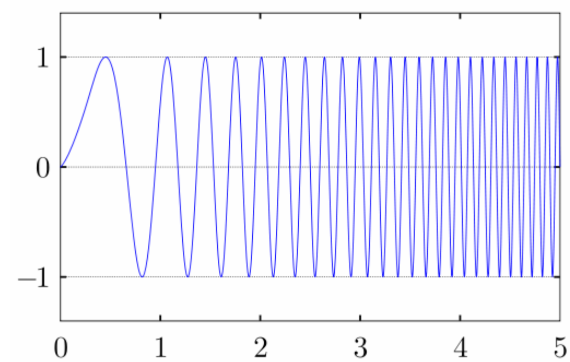


Figure 2: FMCW signal represented as amplitude over time[1]

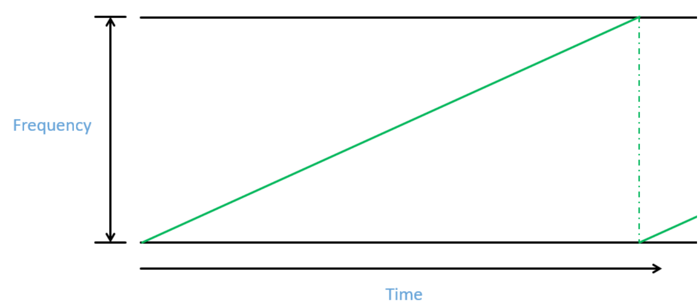


Figure 3: FMCW chirp represented as frequency vs. time

The frequency versus time plot of the FMCW signal tells us several important characteristics of the chirp including: the frequency bandwidth of the chirp, the chirp time, and the slope of the chirp frequency (see Figure 4). These factors are important in adjusting the performance of the FMCW radar. For example, the distance resolution provided by the sensor is proportional to the bandwidth of the chirp (Equation 1):

$$Dres = \frac{c}{2B}$$

D_{res}: distance resolution

c: speed of light

B: chirp bandwidth

Equation 1: Distance resolution

[1] Per APA standard guidelines: A linear chirp waveform; a sinusoidal wave that increases in frequency linearly over time. (28 August 2010). Retrieved from https://en.wikipedia.org/wiki/Chirp#/media/File:Linear-chirp.svg.

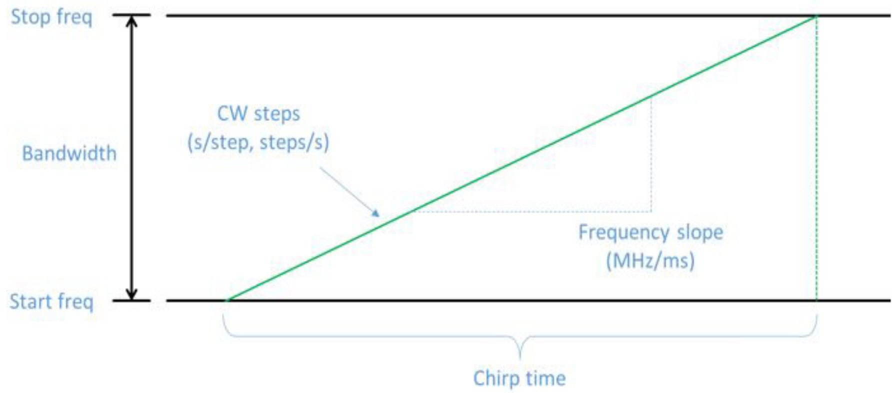


Figure 4: FMCW chirp characteristics

The wider the bandwidth, the finer the resolution that can be detected. The resolution, however, has to be balanced with the maximum distance of the radar, which is directly proportional to the slope of the chirp (or the rate at which the frequency increases), as shown in Equation 2.

$$Dmax = \frac{fc}{2S}$$

f: IF frequency

S: slope of the chirp

D_{max}: maximum distance of a detectable object

C: speed of light

Equation 2: Maximum distance

Therefore, for a fixed chirp time, a wider bandwidth will improve the distance resolution, but it will also increase the slope and hence decrease the max distance and vice versa. In an auto radar application, different chirps can be used for different types of sensors. An application like adaptive cruise control, for example, may need long distance capability to detect cars in lighter traffic, but doesn't need as fine a resolution. Collision avoidance, however, will need to react much faster to rapid changes in short distances, so resolution would be much more important.

Chirp Frames

It is also important to understand the sequence of chirps. Several consecutive chirps is called a frame. Frames can be made up of 10s or hundreds of chirps, depending on the application. These chirps could be uniform or they could be mixed, with some chirps having wider bandwidth and sharper slopes and others with narrow bandwidth and shallow slopes. Frame characteristics can be organized to improve RF performance while making chipsets more power efficient. Multiple chirps in a frame also gives the sensor Doppler information that can be used to calculate velocity. Velocity resolution is improved by increasing the chirp frame time (Equation 3). The length of the frame (or frame time, Tf) will impact the resolution of the velocity that can be detected by the radar. A longer frame (which consists of more chirps) will have a finer velocity resolution.

$$Vres = \frac{\lambda}{2\mathrm{Tf}}$$

Equation 3: Velocity resolution as a function of frame length

The chirps in a frame can be transmitted back-to-back or may have some idle time between each chirp. After each frame, there is typically an "off time" to separate the frame bursts, as well as improve the power and performance of the chipset. Figure 5 shows all these characteristics in a full frame diagram.

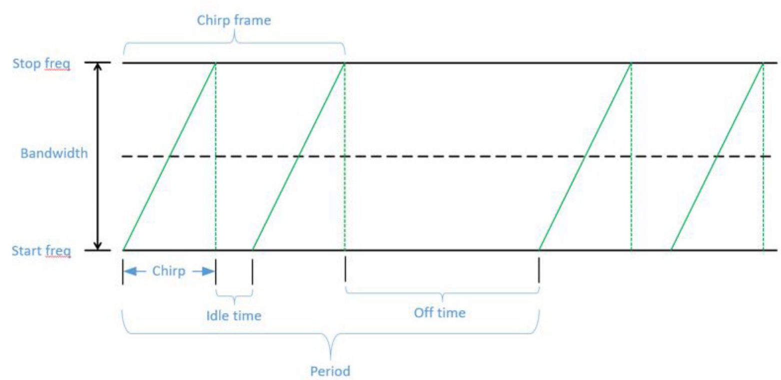


Figure 5: Diagram of frame characteristics

Troubles with Measuring FMCW Signals

In the real world, testing and measuring these different chirp RF characteristics can be difficult. A few factors that contribute to that difficulty are:

- Chirps are changing in frequency very quickly
- Modulation bandwidths can be very wide (up to 10 GHz!)
- RF frequencies are already very high (see Table 1) and research continues to push them higher

Region (Regulator)	Automitve Radar Frequency Bands
Europe (ETSI)	76 - 81 GHz
USA (FCC)	46.7 - 47-9 GHz, 76 - 81 GHz
Japan (MPT)	60 - 61 GHz, 76 - 81 GHz

Table 1: Sample of automotive radar frequency allocation in various regions

Basic Spectrum Analyzers

Most spectrum analyzers are not fast enough to capture chirps in a single sweep. A typical spectrum analyzer will sample and process sequentially, which leaves blind spots where the instrument is not measuring the signal. When a signal like an FMCW chirp is rapidly shifting in the frequency domain over time, it is likely the analyzer will miss movements in the signal during the blind spots (see Figure 6). This will result in the analyzer either displaying no signal, or only displaying parts of the signal, with dropouts in places where changes in the frequency were missed (see Figure 7).

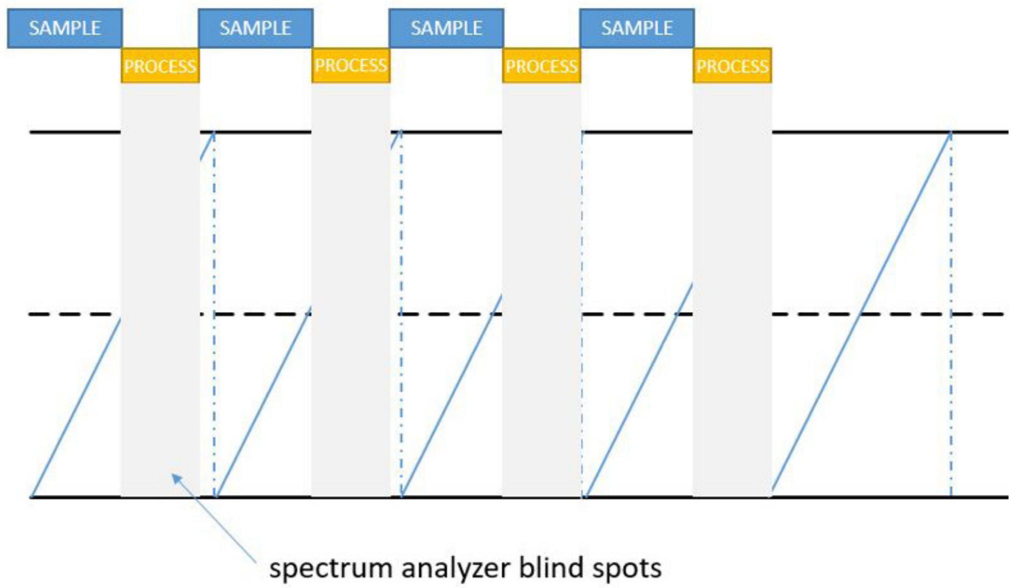


Figure 6: Spectrum analyzers sample and process in sequence and can miss changes in the signal over time

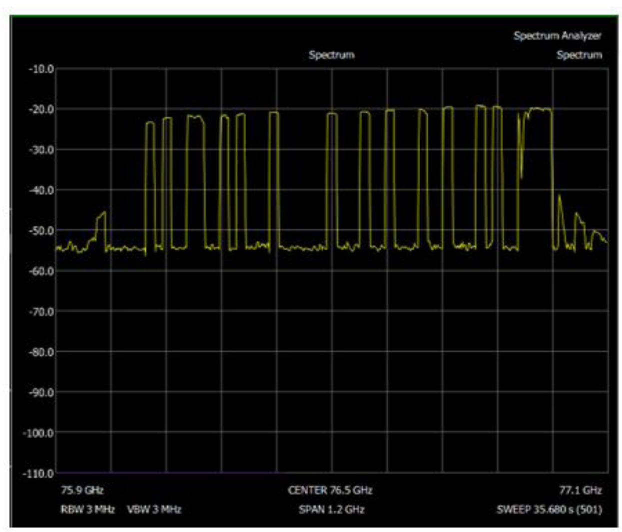


Figure 7: Example of dropouts in a spectrum analyzer measurement of an FMCW signal (amplitude vs. frequency)

Real-Time Spectrum Analyzers

Real-time spectrum analyzers (RTSAs) are a more viable solution because they continuously sample while doing processing in the background, essentially removing the blind spots from the measurement. This makes it much less likely to miss movements of the chirp, however true RTSA measurements are limited to the analysis bandwidth of the instrument, which typically is limited to tens or hundreds of megahertz. Auto radar FMCW chirps can be anywhere from 10s of MHz to 10s GHz wide. If the analyzer is required to have a span wider than the maximum real-time bandwidth, it will have to take multiple samples and "stitch" them together. These samples are taken sequentially, however, so the measurement will have blind spots again.

In addition to the bandwidth limitations, most spectrum analyzers with wider analysis bandwidths typically do not go higher than 43 GHz in frequency range, which precludes them from most FMCW technologies that are typically above 70 GHz.

Oscilloscope sampling

A common technique for monitoring FMCW chirps is a combination of an oscilloscope and spectrum analyzer (Figure 8), where the oscilloscope is fast enough to capture all the time and frequency characteristics of the chirp. An oscilloscope is capable of capturing the fundamental sine wave of the signal, which can be used to break down and produce all the chirp and frame characteristics shown in Figures 2 - 5.

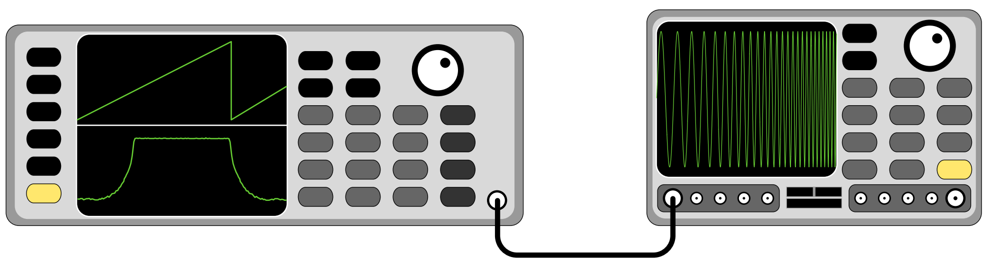


Figure 8: Oscilloscope analyzer combination

While this is the most technically complete solution, it is also by far the most expensive as it requires the purchase of two instruments along with all the software licenses required to connect them and analyze the results. Furthermore, the type of measurements provided by this solution are often more than is needed, especially in production or field environments where basic function tests are the only requirement. Finally, this solution is also bulky and heavy, which can make it difficult to use in chamber or field tests.

Testing FMCW with the Spectrum Master MS2760A

Anritsu's Spectrum Master MS2760A ultraportable spectrum analyzer is a robust solution for measuring FMCW signals. It falls under the "basic spectrum analyzer" category from the previous section, but it has several distinct advantages over other analyzers.

Size and Frequency

First and foremost is its size. The Spectrum Master MS2760A is the only pocket-sized spectrum analyzer with continuous frequency coverage from 9 kHz to 110 GHz. This makes it easy to take to the field for outdoor or chamber tests and simple to integrate into production systems. The size and frequency combination is achieved by using Anritsu's patented non-linear transmission line (NLTL) technology. The NLTL "shockline" receiver creates harmonics at very high frequency that allows the analyzer to sample all the way up to 110 GHz. This means there are no bulky mixers needed for down converting the signal, keeping the form factor as small as possible. Furthermore, most of the signal processing has been pushed to the PC, so there is no need for extra motherboard hardware. This means the Spectrum Master MS2760A can be easily integrated into chamber tests and/or taken out of the labs for a variety of field tests.

Productivity

As discussed, millimeter-wave (mmWave) testing, including automotive radar, can be very difficult. Standalone mmWave spectrum analyzers (i.e., those that do not incorporate harmonic mixers) are extremely complex and expensive. As a result, labs are often forced to time-share equipment. This slows test productivity, which can slow down development and lengthen time-to-market.

The affordable price of the Spectrum Master MS2760A allows companies to place mmWave spectrum analyzers with more engineers, enabling them to work in parallel rather than sequentially, reducing the risk of project delays and unrealistic capital expenses.

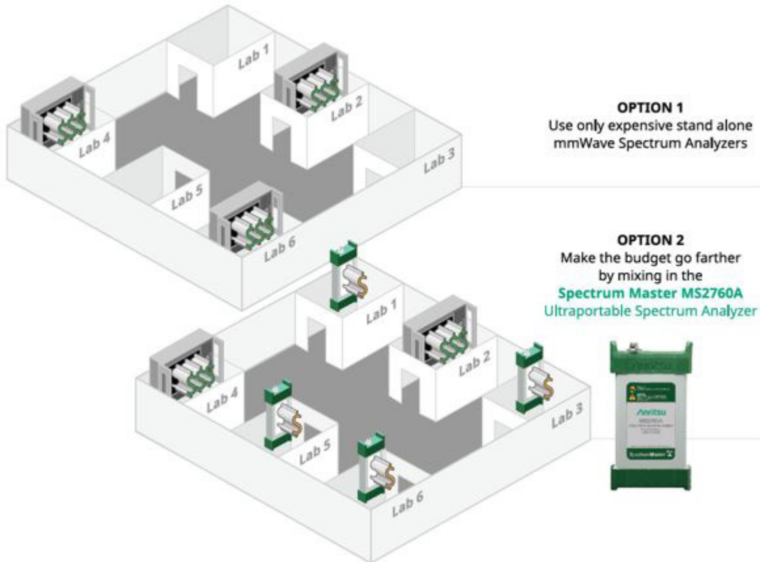


Figure 9: The Spectrum Master MS2760A puts mmWave measurement capability in the hands of more engineers/technicians to drive faster product development

Furthermore, for chamber tests that can run continuously for several days, the Spectrum Master MS2760A can provide constant coverage without tying up unnecessary capital expense. In a situation where equipment is limited, it is difficult to justify monopolizing an extremely expensive piece of equipment for that long. The Spectrum Master MS2760A is a perfect stand-in to monitor any changes in signal power or frequency. With an operating temperature of 0 to 50˚C and built-in temperature calibration factors, under some conditions, it can even be placed in the chamber with the DUT.

Overcoming Measurement Challenges

As previously described, basic spectrum analyzers have difficulty measuring the fast-changing characteristics of FMCW chirps. The Spectrum Master MS2760A overcomes these challenges with several specific features.

Minimum Capture Time

The key to overcoming blind spots in the measurements is to allow the analyzer time to see all the movements in the signal before starting to process. The Spectrum Master MS2760A is an FFT analyzer, which means it captures data 20 MHz at a time and then processes that data with Fourier transforms. If every 20 MHz capture is guaranteed to see a full chirp, there will be no blind spots. This can be managed by setting the minimum capture time of receiver before performing the FFT. Due to the frame period and off times, it is not usually good enough to set the capture time equal to the chirp time. Idle time between chirps and off time between frames create downtime in the signal. If an FFT falls in the off time, it will show a gap in the FMCW envelope. If there are no idle or off times, the min capture time can equal the chirp time, however, if there are off times the capture time must be increased to capture all the idle and/or off times (see Figure 10).

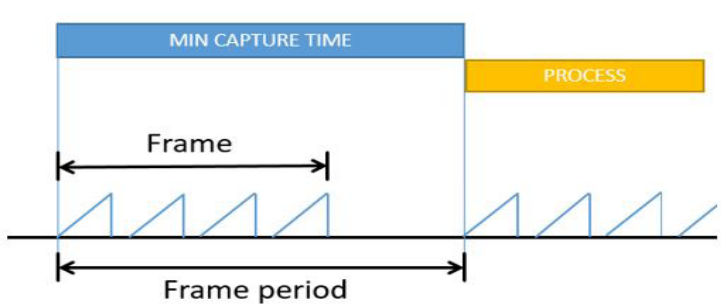


Figure 10: Minimum capture time must capture all down time

With the Spectrum Master MS2760A, this can be done by setting the MIN CAPTURE TIME in the SWEEP menu of the control software. It may be tempting to just set the capture time to a longer time, but it would be ideal to set it as low as possible because longer capture times equal longer sweep times (i.e. longer test time).

Zero Span

When using the minimum capture feature, the Spectrum Master MS2760A provides useful information regarding the overall FMCW transmission (start/stop frequency, bandwidth, amplitude, etc.), but it does not give any information regarding individual chirps or chirp frames. As mentioned before, directly recreating the chirp frame diagram requires an extremely fast receiver, like an oscilloscope. By using the zero span function, it is still possible to gather enough information to derive much of the chirp characteristics manually.

Zero span is an advanced spectrum analyzer tool that essentially zeros in on a single frequency and tracks changes in amplitude at that frequency over time. Figure 11 illustrates how this works with the FMCW chirp. The top diagram shows how zero span is essentially taking a horizontal cross section of the frame diagram. The bottom diagram shows what will appear on the screen of the spectrum analyzer

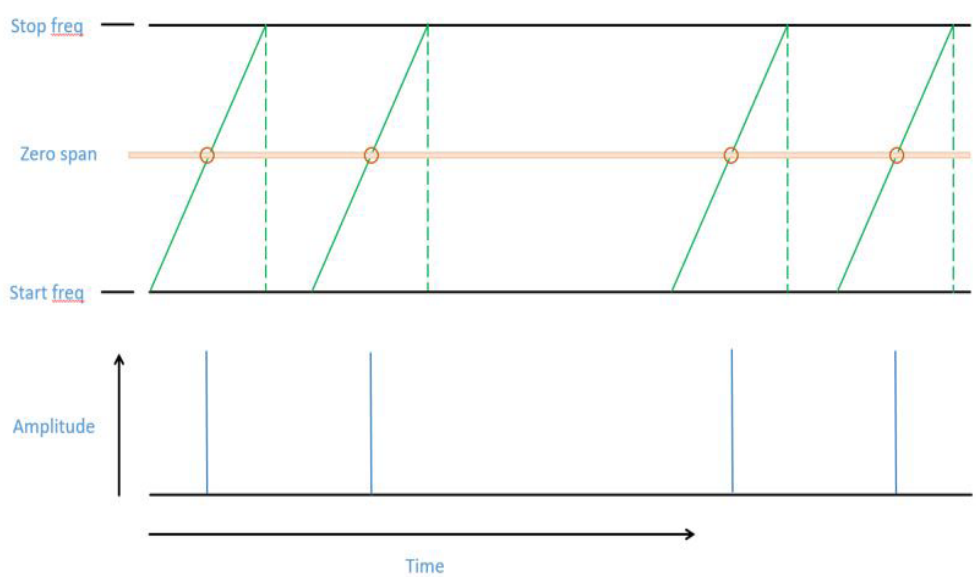


Figure 11: Illustrations of zero span measurements of FMCW radar signals

With this zero span view, basic information can be read to reproduce the chirp diagram of a live FMCW signal, such as frame time, frame period, and number of chirps per frame.

Example

The following is an example of the Spectrum Master MS2760A measuring a 1 GHz bandwidth FMCW chirp over the air from 76 to 77 GHz. The software defaults the instrument to the fastest capture time possible based on the RBW of the instrument. In this case, with a capture time set as low as possible, the analyzer sweeps the 1.2 GHz span in about 350 ms. However, it is unable to see any of the signal (Figure 12)

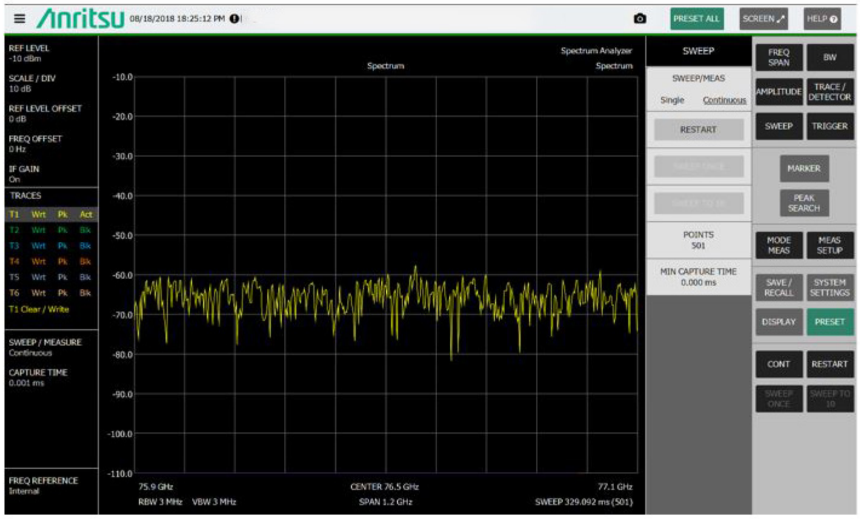


Figure 12: Measuring FMCW with very low capture time no signal is seen

From the SWEEP menu, the MIN CAPTURE TIME can be increased to match or exceed the full frame period. While this will increase the sweep time, the analyzer will be able to see the signal. In this case, the frame period is 50 ms, so the MIN CAPTURE TIME is set to the same. Figure 13 shows the results.

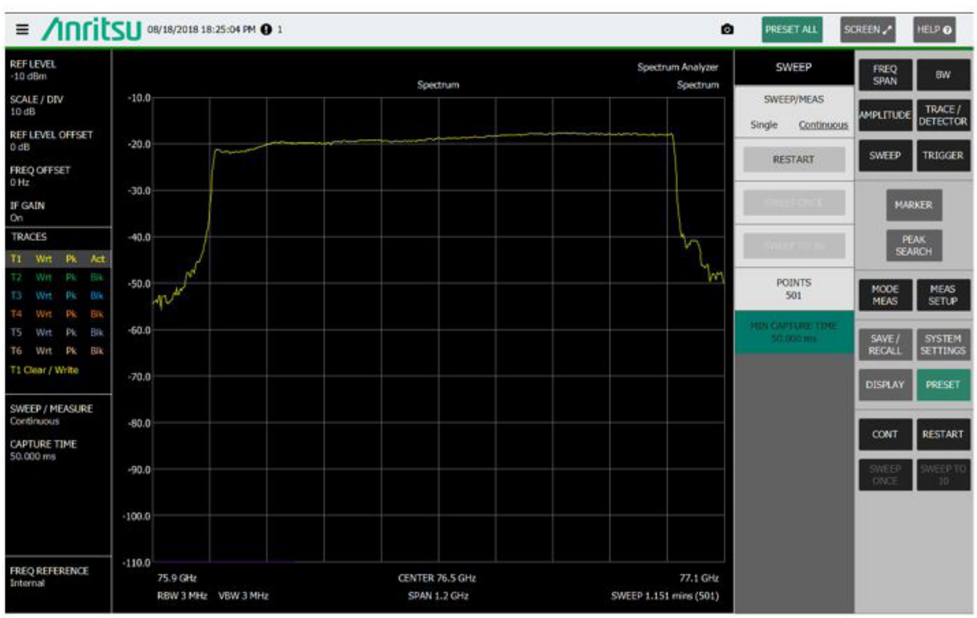


Figure 13: Full FMCW envelope displayed with a capture time equal to the frame period

In a single sweep, the analyzer is able to capture all the movements of the signal and produce a full FMCW chirp envelope. Notice that the sweep time has now increased from 350 ms to 1.15 mins. Decreasing the MIN CAPTURE TIME will improve that sweep speed, but if it goes too low, drop outs will begin to appear, as shown in Figure 7. Note that this is essentially a “max hold” envelope; many cycles of the chirp frame are required to capture the trace. One advantage of this method over a max hold trace, however, is that if the signal is dropped it will be reflected on the sweep. A max hold trace would mask that effect.

Now suppose the required frame period that is needed to set the capture time is unknown. This is where zero span is useful. Figure 14 shows what this chirp looks like when the analyzer is put in zero span mode. In this case, there are two chirp frames shown with the off times in between. By using markers, it is easy to measure the frame time and the frame period. The time between markers 1 and 2 is approximately 15 ms (the frame time) and the time between 1 and 3 is approximately 50 ms, which is the frame period and the value needed for the MIN CAPTURE TIME in the frequency domain.

MARKER	MODE	FUNCTION	TRACE	X	Y
1	Normal	Off	1	-0.236 ms	-19.11 dBm
2	Normal	Off	1	15.229 ms	-17.79 dBm
3	Normal	Off	1	50.000 ms	-50.98 dBm
4	Off	Off		--	--
5	Off	Off		--	--

Figure 14: FMCW chirp frames viewed in zero span

Taking it one step further, zooming in on a single frame gives one more piece of valuable information. Notice the chirp frames are made up of multiple single peaks. Each of these peaks represents a chirp within the frame. Counting the peaks (32 in this case) gives the number of chirps per frame and even the time between each chirp (see Figure 15).

MARKER	MODE	FUNCTION	TRACE	X	Y
1	Normal	Off	1	-0.040 ms	-12.32 dBm
2	Normal	Off	1	0.480 ms	-12.21 dBm
3	Normal	Off	1	0.960 ms	-12.53 dBm
4	Normal	Off	1	1.480 ms	-12.59 dBm
5	Normal	Off	1	1.960 ms	-11.79 dBm

Figure 15: Closer look at one frame in zero span showing the number of chirps in the frame

With just two basic settings, the Spectrum Master MS2760A is able to measure the start/stop frequency, bandwidth, amplitude, frame time/period, and chirps per frame of this basic automotive radar signal. Generally, this is more than enough information to conduct basic function tests of an FMCW transmitter in the lab, in production, and even in the field.

Conclusion

FMCW radar is revolutionizing object detection technology in many spaces, especially automotive radar. However, RF measurement of this complex modulation scheme can be complicated, expensive, and time consuming. The Spectrum Master MS2760A ultraportable handheld spectrum analyzer is an excellent tool for basic FMCW radar test, combining useful measurements with unmatched size and convenience.

Notes

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