METAMAGNETICS®

MAINTAINING RECEIVER FRONT-END LINEARITY IN A DENSE ELECTROMAGNETIC SPECTRUM ENVIRONMENT

Introduction

The Autotune Filter (AtF) is a novel passive electromagnetic interference device. It provides suppression of multiple simultaneous interfering signals while small signals within its instantaneous operating band pass through unaffected. This capability effectively enhances the dynamic range of receivers, enabling them to process a much wider power range of input signals than previously. This technical brief describes the basic functionality of autotune filter and introduces several variations and performance metrics of the technology. These devices are particularly useful in communications and sensing to help ruggedize receivers against the increasingly congested and rapidly evolving electromagnetic spectrum.

Background

The electromagnetic spectrum (EMS) is a valuable and limited resource. The number of devices and systems that rely on the EMS to sense the environment or communicate with each other is increasing rapidly. As a result, the frequency of intentional and unintentional EMS interference cases is on the rise. Mitigating EMS interference is essential for extracting the most value out of the spectrum; but no single approach is effective in all cases. State of the art wireless devices and systems rely on a layered EMS interference scheme consisting of both analog and digital methods including radiation pattern control, frequency filtering, adaptive power management and gain control, sophisticated modulation formats, and adaptive digital cancellation techniques. The overall effectiveness of this layered scheme requires a high degree of receiver analog front-end linearity so that received signals can be digitized with as little distortion as possible.

Means of EMS Interference Mitigation

The range of signal power levels, or the dynamic range, that a receiver can process is limited in practice. In a dense EMS environment, the receiver may be subjected to drastically different signal powers. While the transmit power level is regulated the great diversity of communication protocols, physical implementations, deployment locations, and many other factors to include intentional interference still allows for situations where the range of signal powers can exceed the receiver dynamic range, see figure 1 (a). When this happens, the receiver may become “desensitized,” meaning that weaker signals that the receiver is trying to receive fall under the detection threshold.

Radiation pattern control – the system can reconfigure itself so as to reduce its gain in the direction of the interferer while maintaining or even increasing the gain in the direction of signal of interest. This technique is very effective but typically requires multiple radiating elements and sophisticated signal processing and beam forming capability to implement. Multiple elements typically imply significant physical footprint and the signal processing and beam forming capability imply significant cost, which may not be appropriate for some systems.

Power limiting and automatic gain control – limiting the maximum input power to the receiver can be achieved using a relatively simple PIN diode. However, when a PIN diode limiter is tripped it generates spurious output that contaminates the received spectrum. Therefore, PIN diodes are typically used to protect the receiver from physical damage but operation while diode is tripped is not possible. Automatic gain control (AGC) is a scheme that enables the receiver to detect the maximum input power level and if it exceeds a certain threshold apply attenuation to bring it back into an easier to process range. Unfortunately, all signals experience the same attenuation, which may cause the already weaker signal of interest to fall below the detection threshold, see figure 1 (b).

Frequency filtering – suppressing signals based on their frequency content is extremely common and effective provided there is no overlap between the interferers and the signal of interest. There is a wide variety of different filter technologies but in general reducing filter size leads to increased stopband leakage. This implies that if an interferer is strong enough a filter alone may not be able to suppress it enough for it not to interfere with the receiver. Most filters in use today are fixed, meaning that their passband or stopband cannot be adjusted while in operation. This means that if the source of interferer changes or additional unforeseen interferers are encountered the filter may become ineffective. Tunable or reconfigurable filters are significantly more complex and require additional hardware and signal processing to identify the interferer and configure the filter to mitigate it.

The ability to suppress signals based on their power level offers new capability and flexibility in receiver design, see figure 1 (c). Unlike AGC, suppression can be selectively applied to interferers but not signals of interest to make sure these signals remain above the threshold of detection and the entire spectrum can be sampled and further processed in the digital domain. If this functionality can be achieved with a compact and passive component the implications in receiver design and interference mitigation would be far reaching.

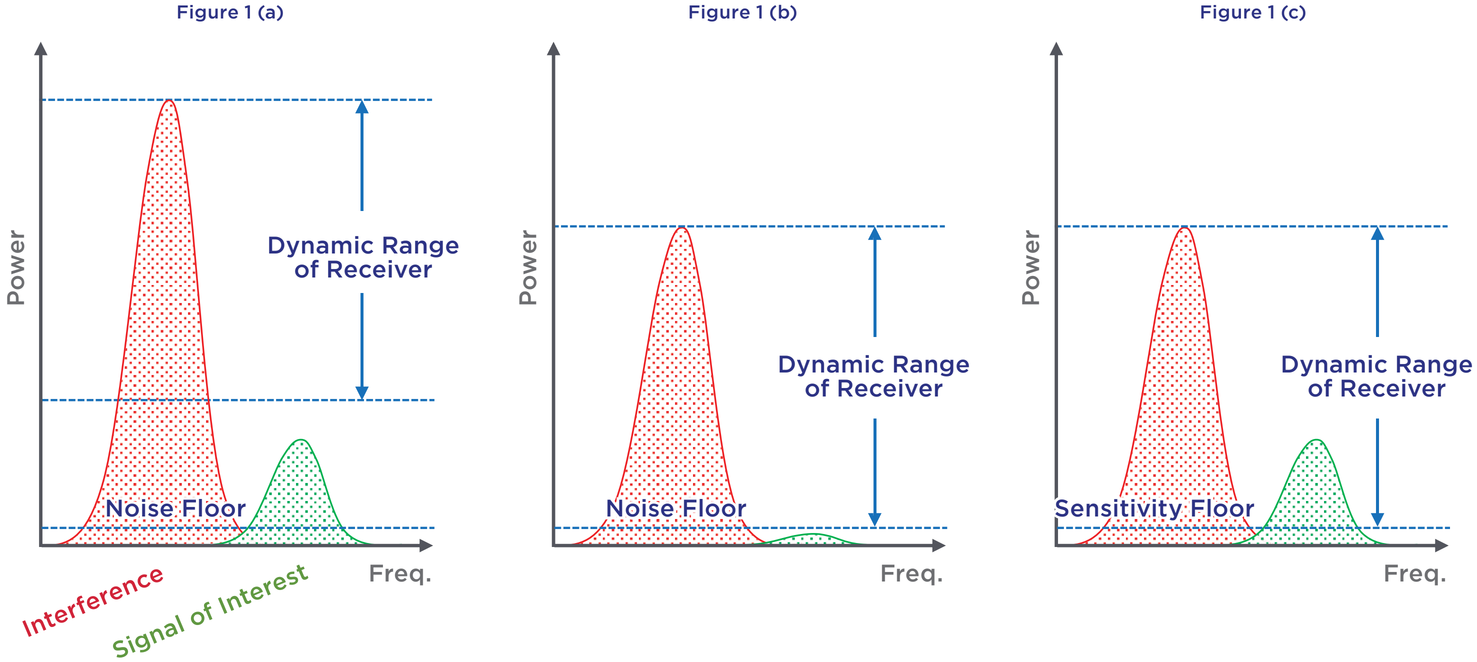


Figure 1 (a) High power interference creates a range of input power levels that exceed the dynamic range of a receiver, resulting in desensitization and loss of signals of interest. **(b)** High power interference is often mitigating using automatic gain control (AGC). AGC applies equal attenuation to all receiver input signals. This may result in the signal of interest falling below the threshold of detection of the receiver. **(c)** The ability to suppress high-power interference without degrading smaller signals of interest enables the receiver to process both signals. This is the behavior of the Autotune Filter that achieves this functionality in a passive analog device.

Autotune Filter

The Autotune Filter (AtF) takes advantage of precisely controlled nonlinearity in certain types of magnetic crystals to achieve power-dependent and frequency-selective EMS interference mitigation, **see Figure 1 (c)**. A power threshold of limiting can be specified during the design and manufacturing of an AtF device. When all input signals to the device are below the power threshold, the device acts as a passive all pass filter, **see Figure 2 on next page**. It introduces small signal insertion loss but doesn't distort the phase of small signals. The magnitude of small signal insertion loss depends on several factors, such as whether the device is configured for reflection or transmission, its instantaneous operating bandwidth, dynamic range, etc.

When signals input to the device exceed the power threshold of limiting the device responds spontaneously to suppress those signals back down to the power threshold. The suppression takes place by either reflecting the excess energy at the input or attenuating it within the device. The suppression process is highly frequency selective and appears as multiple notched formed in the frequency domain transfer function of the device, see figure 3. This implies that small signals within the instantaneous operating bandwidth of the device are not impacted as long as there is sufficient separation in frequency between small signals and large signals being suppressed. The separation of signals is considered sufficient when the small signal is located in frequency outside of the notch formed in response to the interferer. The width of the notch will depend on the interferer power level above the threshold of limiting and its spectral content. In figure 3 the interferers are single continuous wave tones. The depth and width of notches formed in response to those interferers varies depending on the power of the interfering signals above threshold. For more wideband interferers the width of the notch will adjust to include the entirety of the spectral content of the interferer. The minimal width of the notch for a given interferer power level is a finite value depending on the construction of the AtF device. There is no limitation on the number of interfering signals that can be suppressed at any given point in time and no prior knowledge of interferer frequency or spectral content. As long as the total integrated power of the interferer exceeds the power threshold of limiting the device will respond by attenuating it down to the threshold value. Achieving this function in a passive device is uncommon and underscores the utility of AtF in EMS interference mitigation.

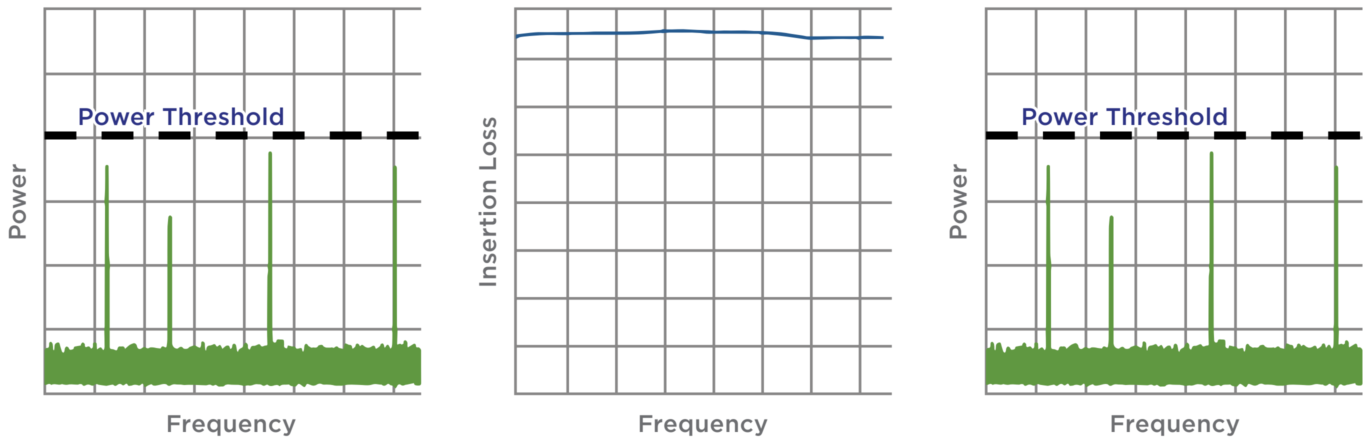


Figure 2 An Autotune Filter behaves as an all-pass filter (center) when all the signals in the incident spectrum (left) are below the designated power threshold of limiting. The output spectrum (right) is only impacted by the small signal insertion loss and experiences no distortion or dispersion of any kind.

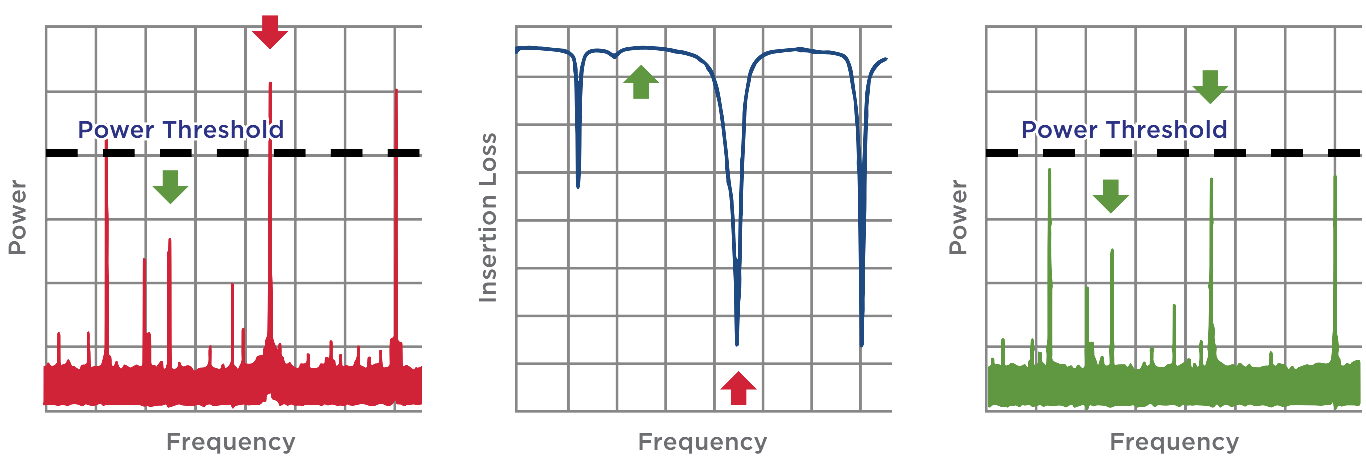
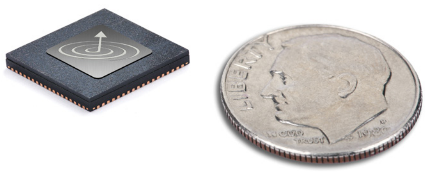


Figure 3 An Autotune Filter responds by forming suppression notches (center) for each input signal that exceeds the power threshold of limiting (left). The depth and width of each notch is dependent only on the power level and spectral content of the interferer above threshold. In the output spectrum of the device (right) the interfering signals have been reduced to the threshold value while the small signals at other frequencies are not impacted by the suppression.

Figure 4 lists the typical performance metrics and form factors of reflective and absorptive AtF devices. These performance metrics and their implications on systems design are discussed in more detail in subsequent technical briefs. The values provided in Figure 4 are meant to serve as general design guidelines and do not imply hard fundamental limitations of the technology.



REFLECTIVE FSL:
Transduction of EM signals into magnetostatic waves

ABSORPTIVE FSL:
Coupling of EM signals directly to spin waves

METRIC	REFLECTIVE FSL	ABSORPTIVE FSL
Notch Width	2 MHz	50 MHz
Response Time	150 ns	30 ns
Size	Smaller (e. g. 1 x 1 x 0.1 cm)	Bigger (0.5 x 0.5 x 5 cm)
Type of Limiting	Reflective	Absorptive
Group Delay	1 to 100s ns	<1 ns
Operating Frequency	0.1 to 6.0 GHz	2 to 18 GHz
Power Threshold	-60 to 0 dBm	-5 to +40dBm

Figure 4 Typical performance metrics and form factors of reflective and absorptive Autotune Filter devices.

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