Matched Filter Detection and Identification of Electronic Circuits Based on their Unintentional Radiated Emissions

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Abstract— **This paper describes a method for detecting electronic circuits based on their unintentional electromagnetic emissions. This concept can be applied to help find hidden electronic devices such as video cameras, active microphones, timers and computers.**

Keywords-matched filter; circuit detection; regenerative receivers; circuit detection.

I. INTRODUCTION

Electronic devices, particularly those that employ digital circuits or work at RF frequencies can be significant sources of unintentional electromagnetic radiation. EMC engineers, who spend a lot of time measuring unintentional electromagnetic emissions from electronic products, generally learn to recognize particular devices or circuit configurations by the electromagnetic "noise" that they generate. In fact, if people had ears that could hear electromagnetic emissions as easily as they hear acoustic emissions, we would quickly learn to associate particular electromagnetic "sounds" with the devices that generate them.

With the help of an RF receiver and a little signal processing, it is possible to convert electromagnetic radiation signals to acoustic signals that can be heard. In fact, EMC engineers have used this technique for decades to help identify and isolate sources of electromagnetic emissions. This is why many EMI receivers and spectrum analyzers come equipped with AM and FM demodulation circuits and speakers.

In addition to demodulation, RF signals can be converted to acoustic signals by capturing them and playing them back with the time scale slowed by a factor of 10^5. This translates RF frequencies to acoustic frequencies and the signals can be used to drive a speaker or headphones. Using this simple technique, it has been shown that a variety of electronic devices can be detected and identified simply by "listening" for them [1].

With additional processing, background noise and signals from known, unimportant signal sources can be attenuated making it easier to "hear" unusual signals even when they are much weaker than the ambient noise.

If we know what particular device (or devices) we are trying to detect, we can block out other signals very effectively using matched filters. A matched filter has an impulse response

$h(t)=s(T-t)$ and it designed to detect a signal s(t) with optimum signal-to-noise ratio. This paper describes a technique for detecting electronic circuits based on their unintentional radiated emissions using matched filters.
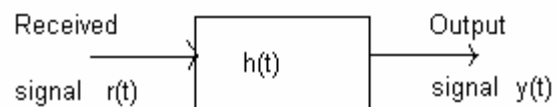
Figure 1. Matched Filter.

II. MATCHED FILTERS

A linear time-invariant (LTI) filter with impulse response $h(t) = s(T - t)$, where s(t) is assumed to be confined to the time interval $0 \le t \le T$, is called the matched filter to the signal s(t) [2]. For the matched filter illustrated in Fig. 1, the output y(t) in response to an input signal **r**(t) is

$$y(t) = h(t)*\mathbf{r}(t)$$

$$y(t) = \int \mathbf{r}(\tau)\, h(t-\tau)\, d\tau \tag{1}$$

$$= \int \mathbf{r}(\tau)\, s(T-t-\tau)\, d\tau.$$

If the received signal is,

$$\mathbf{r}(t) = s(t) + n(t) \tag{2}$$

where n(t) is the noise, then

$$y(t) = \int s(\tau)\, s(T-t-\tau)\, d\tau + \int n(\tau)\, s(T-t-\tau)\, d\tau. \tag{3}$$

The first part of (3) is the signal portion and the second part of (3) is the noise present at the output of matched filter. The signal portion is the time autocorrelation of the signal s(t), which exhibits the maximum possible signal power. Since the noise generally has different properties than the signal, the signal-to-noise ratio is usually much greater at the output of the matched filter than at the input.

By converting the output of a matched filter to an acoustic signal, it is possible to listen for the presence of a particular device. In laboratory tests performed by the authors, specific devices could be audibly detected much more easily using a matched filter. However, when attempting to detect a variety of

devices simultaneously, it is more effective to employ a bank of matched filters and an automated detection scheme as described below.
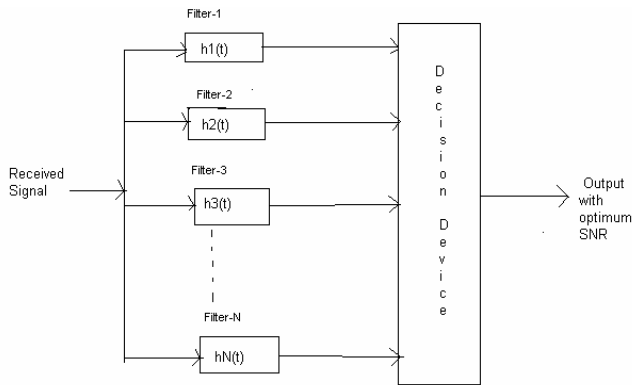

Figure 2. Bank of matched filters which are used to detect multiple electronic devices.

III. BANK OF FILTERS TO DETECT MULTIPLE DEVICES

Suppose that there are N electronic devices each with unique radiation properties. Let the signals of the N devices be represented by,

$$s1(t), s2(t), \ldots ,sN(t). \qquad (4)$$

N matched filters with impulse responses equal to,

$$h1(t) = s1(T\text{-}t), h2(t) = s2(T\text{-}t), \ldots hN(t) = sN(T\text{-}t), \qquad (5)$$

as indicated in Fig. 2,can be used to detect the respective signals from these devices.

A. Detecting a single device in the presence of noise

If the received signal is

$$r(t) = s1(t) + noise, \qquad (6)$$

then only Filter 1 with an impulse response h1(t) gives the optimum response. By comparing the power levels of signals from the outputs of all the filters, the output from Filter 1 should be significantly higher than the outputs from the other matched filters, indicating that the received signal contains only s1(t). We can define a threshold power level based on our knowledge of the signal we are searching for and our observations of the ambient noise. When the output of Filter 1 exceeds this threshold, Device 1 is detected.

B. Detecting multiple devices in the presence of noise

Let the received signal be

$$r(t)=s1(t)+s2(t)+noise. \qquad (7)$$

In this case, both Filter 1 and Filter 2 will exhibit an optimum response and the outputs of the other filters will exhibit lower power levels. By properly setting our threshold, we will recognize that both Device 1 and Device 2 are present.

C. Detecting the absence of devices

Let the received signal be,

$$r(t) = noise1 + noise2. \qquad (8)$$

In this case, if our threshold power was appropriately defined based on the measured ambient, the output power levels of all the filters will be less than the threshold indicating that none of the N devices has been detected.
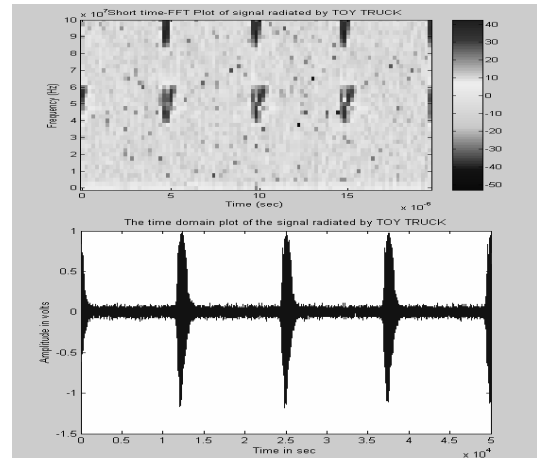

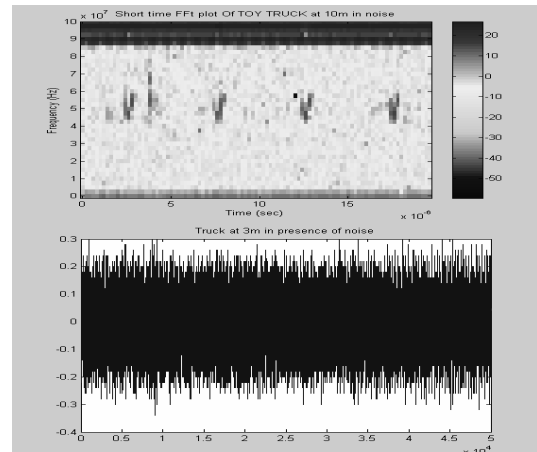Figure 3. Emissions from remote-controlled toy measured in the chamber.

Figure 4. Emissions from remote-controlled toy 10m away in presence of noise.

IV. MEASUREMENTS

Three electronic devices were measured in a semi-anechoic environment in order to obtain signal data for constructing a matched filter. All three devices were simple RF receivers that were functionally similar, but had unique applications. The devices tested were:

- a receiver for a remote-controlled toy

- a wireless door bell receiver
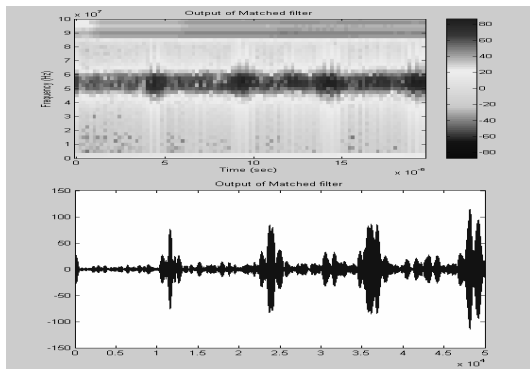
- a wireless alarm receiver.

Figure 5.   The filtered signal from the remote-controlled toy 10m away in presence of noise.

Figure 3 shows the time domain signal and a short-term FFT plot of the emissions coming from the remote-controlled toy. The measurement was made at a distance of 3 m in a semi-anechoic chamber. The short-term FFT displays the frequency content of the signal (vertical axis) versus time (horizontal axis). The time window is 20 μsec. The regenerative receiver used in this application exhibits a pulse of energy approximately every 5 μsec primarily at frequencies near 55 MHz and 95 MHz.

Figure 4 shows a measurement of the same remote-controlled toy at a distance of 10 meters outside the semi-anechoic chamber in a long corridor. Note that the ambient noise in the corridor completely overwhelms the signal as viewed in the time domain. The short-term FFT reveals the presence of the receiver, because the pulses of energy near 55 MHz are still clearly visible. The 95 MHz energy however, is hidden by electromagnetic emissions from local FM radio stations.

Filtering the data in Figure 4 using a matched filter based on the data in Figure 3, results in the output shown in Figure 5. Although the signal from the toy measured in a corridor at a distance of 10 meters is not exactly the same as the signal measured in a semi-anechoic environment, the matched filter is able to extract the essential elements of the received signal. If this output is converted to an audio signal, it is easily identifiable as the toy. To make an automatic identification, the output power can be compared to a predetermined threshold.
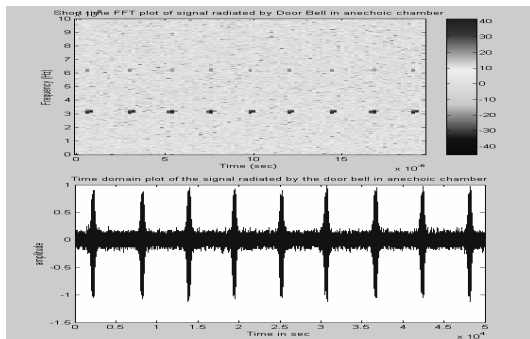

Figure 6.   Emissions from wireless door bell measured in the anechoic chamber
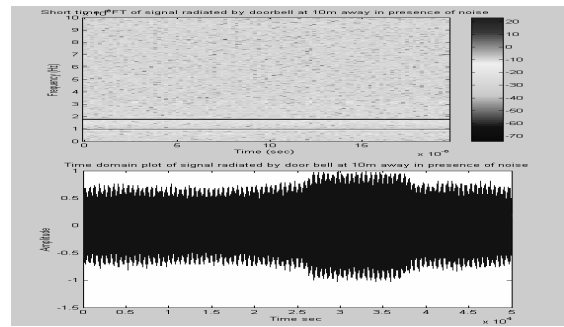

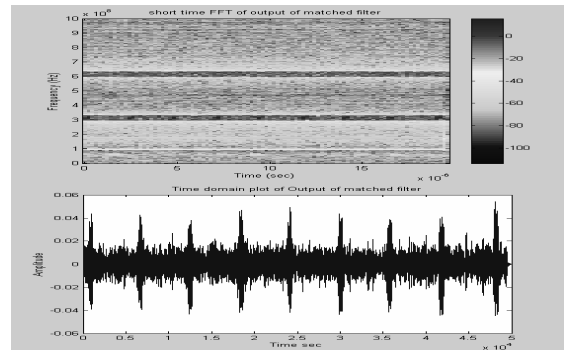Figure 7.   Emissions from wireless door bell 10 m away in presence of noise.

Figure 8.   The filtered signal from the wireless doorbell 10m away in presence of noise.

Figures 6-8 show similar data obtained for a wireless doorbell receiver. This device also employs a regenerative receiver and exhibits a burst of emissions every 2.3 μsec primarily at 31 MHz. A matched filter does an excellent job of recovering this signal from the noise in the corridor.

Figures 9-11 show the measured radiated emissions from an alarm receiver with bursts of energy primarily in a frequency band from 40 to 45 MHz occurring every 0.5 μsec. Although the output of the matched filter appears noisy in the plot, it is easily identified by listening to an audio representation of the output or by comparing the output power to a predetermined threshold.
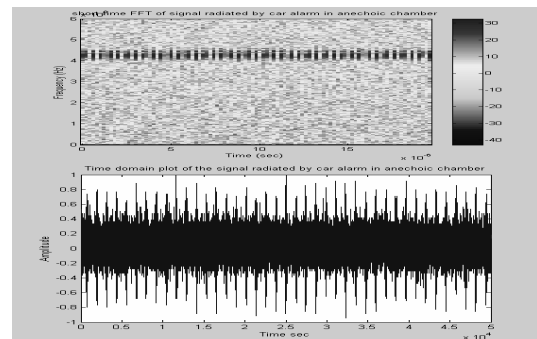

Figure 9.   Short-term FFT and time domain plots of alarm measured in the anechoic chamber
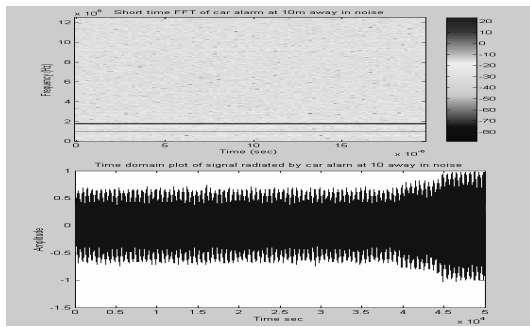
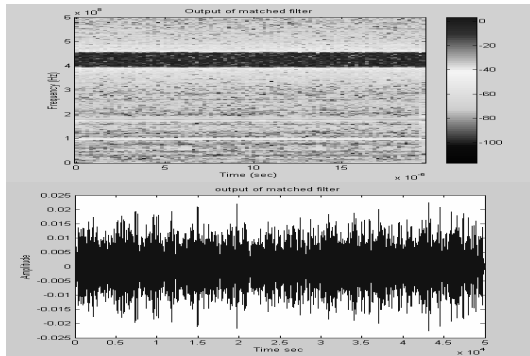Figure 10. Short-term FFT and time domain plots of alarm at a distance of 10 m in the presence of noise.

Figure 11. The filtered signal from the alarm at 10m in the presence of noise.

Although the devices tested here all employed regenerative receivers, this technique can be applied to the detection of other types of RF receivers and digital circuits. Emissions from a wide variety of devices have been measured by the authors [1].

V. CONCLUSIONS

The unintentional emissions from electronic devices can often be used to detect the presence of these devices and identify them. To detect and identify a finite number of known sources, matched filters can be used to extract weak signals from the ambient noise.

REFERENCES

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[2] John Proakis, Digital Communications, 4 Edition,McGraw-Hill, 2001.