ShotSpotter Whitepaper

ShotSpotter® Flex(SM)

September 2, 2014

Gunshot Detection Technology

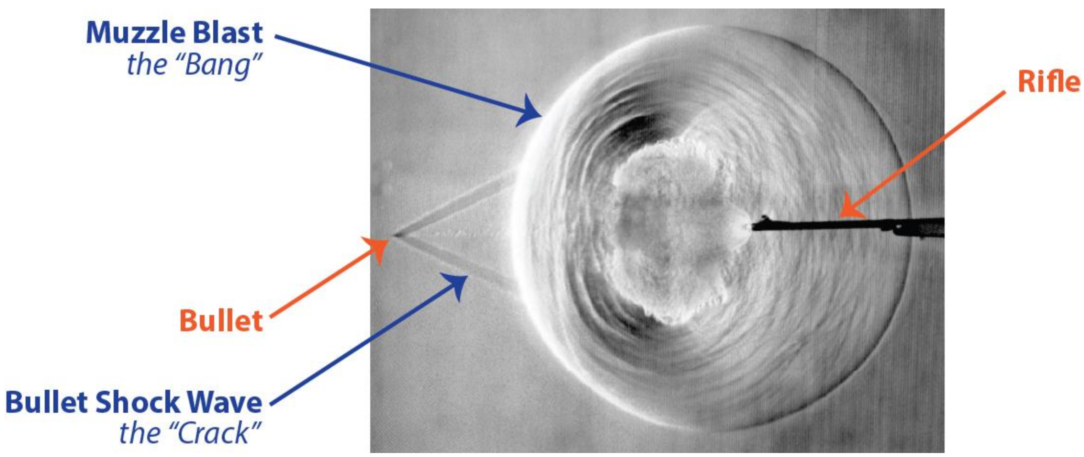
Gunshot Technology – Hammers or Pliers? Depends on the task at hand

Technology that detects gunfire has existed for nearly two decades. Many approaches have been tried, in part because different users require different information. For example, a soldier on the battlefield needs to know the direction and approximate distance of whoever is firing at her. By contrast, a police captain needs to know what gunfire is happening anywhere across a big city. In part because of these different requirements, different scientific approaches were applied, and as a result, there are different techniques that work in different environments and for different needs. Those different techniques bring with them a classic *there is no free lunch* trade-off: what works well for a particular use case (for example, when one is protecting a small target from a shooter likely to be nearby) will generally not work for a different use case (for example, when one seeks to protect and an entire city neighborhood). These different approaches use different scientific principles, produce different results, and thus are appropriate for different circumstances. Keep reading to learn more about how they differ.

ABOUT GUNFIRE SOUNDS

Although the technologies developed to detect gunfire are each quite sophisticated, the physical events they measure are fairly basic: systems can measure the *sound* (acoustic) or the *light* or *heat* (optical). Because optical systems are, by their nature, line-of-sight only, they generally don't play much of a role in urban environments. They tend to be quite expensive (tens if not hundreds of thousands of dollars per sensor), and specialized (mostly for military use). We will focus on acoustic gunshot detection instead.

Acoustic gunshot detection principally works by detecting a sound created by the gunfire. Note that we said *a* sound, not *the* sound: although we commonly think that "guns go *bang*", it is in fact the case that they nearly always go *bang* but they also sometimes make a second noise, commonly called a supersonic *crack* or the *snap*, depending on the type of ammunition used. Have a look at this photo[1], taken by a special process called *schlieren photography*, which permits photos to be made of pressure waves (*i.e.* sounds) as they move through the air:

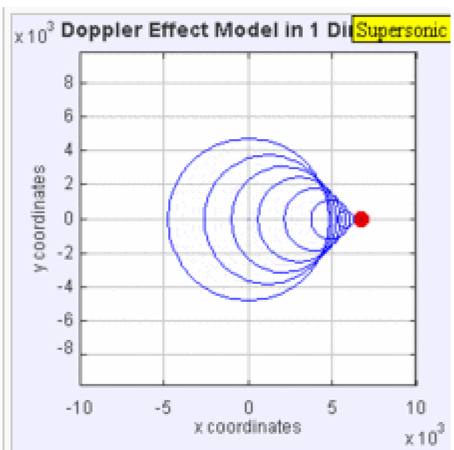


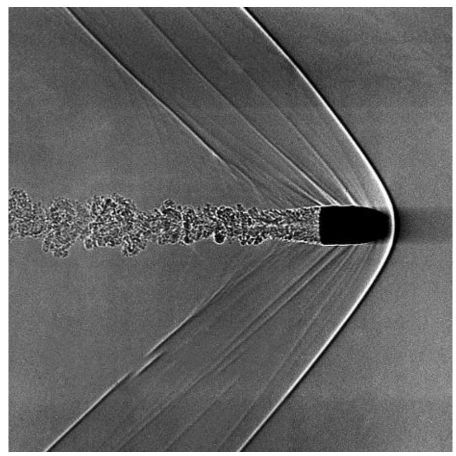
The *muzzle blast* is the noise we commonly associate with gunfire. It is the Hollywood gunfight sound effect that goes *bang*. **Unless a suppressor is used, all guns produce a**

[1] Photo credit: Settles *et al*. "Full-scale high-speed schlieren imaging of explosions and gunshots" 2004 http://www.me.psu.edu/psgdl/Pubs/2004-Settles-CHPP.pdf

loud muzzle blast. (Even when a suppressor is used, there is a noise, Hollywood's sound effects notwithstanding.) Muzzle blasts are *loud*: at the muzzle they can measure 160dB or higher, and they can be heard one to two *miles* away, depending on conditions. Like all other sounds, they refract around buildings and terrain: generally speaking, muzzle blasts can be heard without line-of-sight.

In some cases, a second loud noise is produced by the bullet itself. If the bullet is traveling faster than the speed of sound, then it produces a *supersonic bullet noise* (a *crack),* also known as the bullet bow shockwave, which is perhaps more familiar as the sonic boom produced by an aircraft traveling faster than the speed of sound.





Unlike the sonic boom from an aircraft, this *crack* noise is audible only for a distance of some 30-50 meters (about 100-165 feet) away from the path of the bullet, and only for so long as that bullet travels supersonic (faster than the speed of sound). Inevitably, the bullet slows down due to air resistance (or due to impact), at which time the crack is no longer audible.

Summary of Acoustic Phenomena Produced by Gunfire

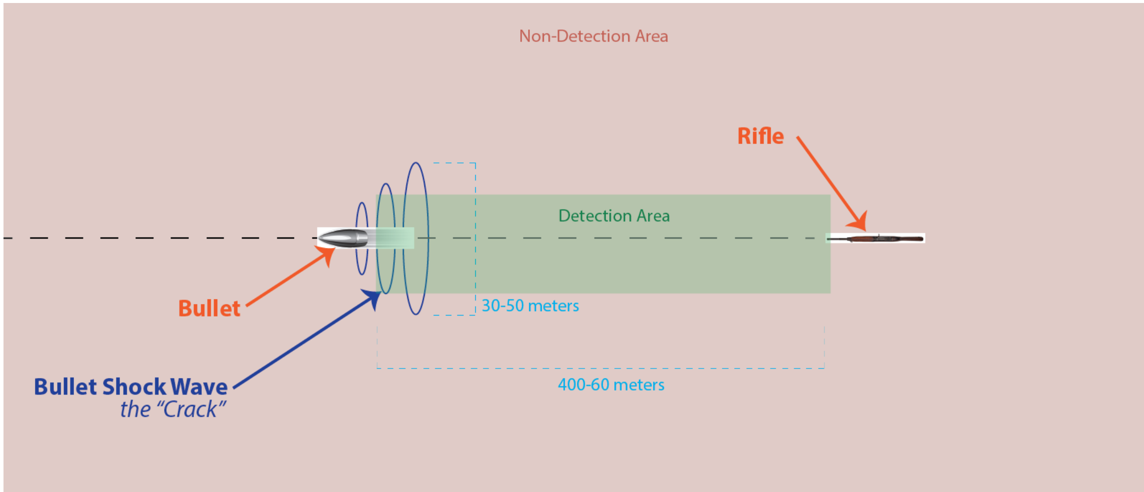
	Muzzle Blast	*Supersonic* Crack
Guns	All guns	Some guns w/supersonic ammunition
Bullets	All bullets	Supersonic ammunition
Audible	In all directions	Only along bullet trajectory

Distance Audible	1-2 miles (1.6-3.2km)	100-165 feet (30-50 meters)
Other	Refracts around buildings Does not require line-of-sight Loud at source but quiet far away	Stops when bullet slows below supersonic (usually 400-600 meters) Unique and loud
False Positives	Require filtering or other post-detection review	Relatively few
False Negatives	Relatively few	All subsonic bullets are potential false negatives

Gunshot detection technologies are fundamentally divided into those two basic camps: *muzzle blast detection* and *supersonic crack* detection.

SUPERSONIC *CRACK*: MILITARY COUNTER-SNIPER TECHNOLOGY FOR SMALL AREAS WITH LINE-OF-SIGHT TO ASSAILANTS

In the late '90s and early 2000s, a number of supersonic detection technologies were developed which detect supersonic bullets as they fly past a sensor. These so-called *counter-sniper sensors* have been used successfully in military deployments by many countries. In such cases, the sensors providing the detection capability are deployed in the same place as (*i.e.* "collocated with") the very thing that is the target of the sniper—*e.g.* a Humvee or an individual soldier. To put it another way, counter-sniper technology makes an *a priori* assumption that the counter-sniper sensor will be deployed *in the line of fire*.



There is also a second assumption: the bullets will be supersonic. Not all bullets are, and not even all bullets fired from military assault rifles are supersonic. Nevertheless, counter-sniper technology developers know that the weapon(s) of choice for military or insurgent assailants are likely to produce supersonic gunfire. Within this narrow definition of use, the advantages of the counter-sniper approach is that it produces very few—if any—false positives (because very few other objects are moving supersonic and thus there are not many acoustic events that could be mistaken for the supersonic *crack* created by a bullet breaking the sound barrier). Moreover, because the sensor is actually in the line of fire, the bullet noise reaches the sensor virtually instantaneously, permitting an answer to be calculated within far less than a second (often 0.1 seconds or less).

Most counter-sniper systems identify the direction (angle and elevation) from which the shot occurred. In some cases, the technology is further advanced by also determining the distance (range) of the shooter using sophisticated mathematical calculations combining the leading edge and trailing edge of the bullet bow shockwave, the curvature of the shockwave front itself, the speed of the projectile itself, or a combination of all three. Such techniques estimate range but generally require a specific *ballistics table* for each and every type of ammunition the sensor is designed to detect.

FEW FALSE POSITIVES BUT NARROW APPLICABILITY

The disadvantage of the counter-sniper approach is that it produces low false positives by filtering out anything which isn't:

a) Supersonic;

b) On a trajectory that passes within 50 meters of the sensor; and

c) Close enough that the bullet is still traveling faster than the speed of sound.

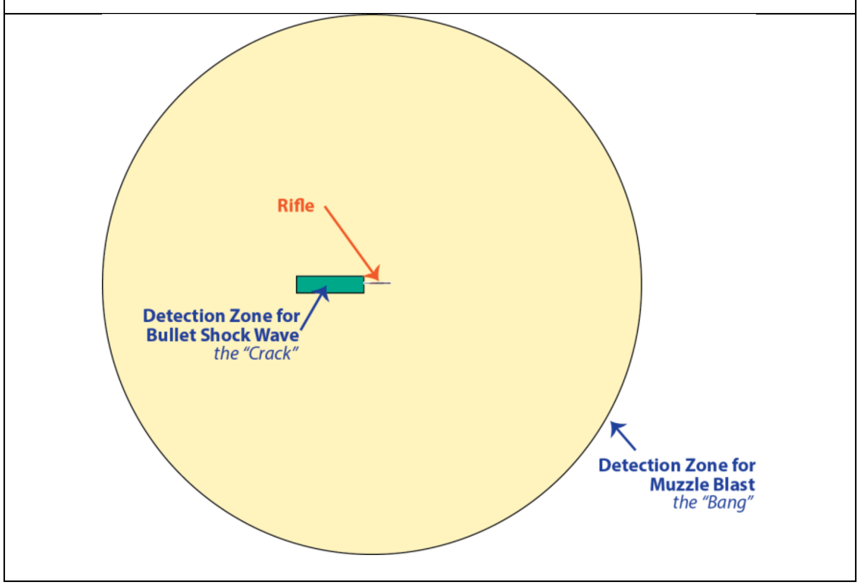
If *any* of those three requirements is missed—or if the assailant simply chooses subsonic ammunition, for example—then there will be an incomplete or non-existent detection. For most military uses, this disadvantage isn't a disadvantage at all. Except for special operations attacks, military enemies and insurgents use supersonic assault rifle ammunition and sniper ammunition. Thus the disadvantage is managed by the application or use case of the technology: In military applications it is an appropriate expectation that the snipers are using supersonic ammunition and firing weapons *at* the sensor target that happens to be collocated with the sensor itself.

MUZZLE BLAST: NON LINE-OF-SIGHT, WIDE AREA PROTECTION

By contrast, muzzle blast detection works at long range. Muzzle blast sensing technology generally falls into two categories: *single point sensors* which operate in close proximity to the gunfire source, or *distributed sensor arrays* which collaborate to produce detections. Both approaches detect the muzzle blast and have the ability of hearing a gunfire boom or bang as far away, but as we'll see, the similarities end there.

In non-battlefield settings, muzzle blast approaches have the advantage of covering much larger areas with comparatively few sensors, as well as permitting bullets to be fired in any direction (at the sensor or not).

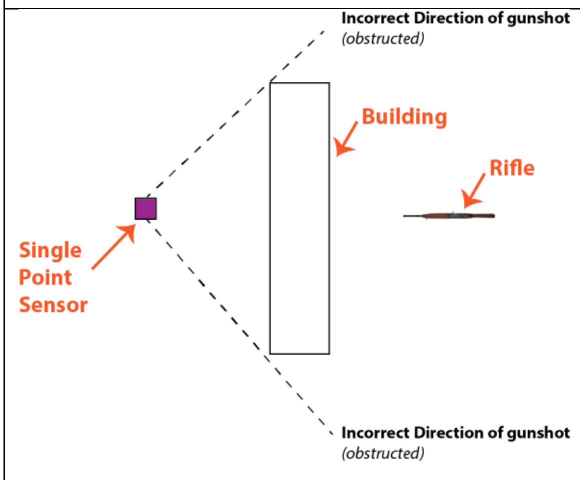
Coverage Area: Muzzle Blast versus Supersonic Crack



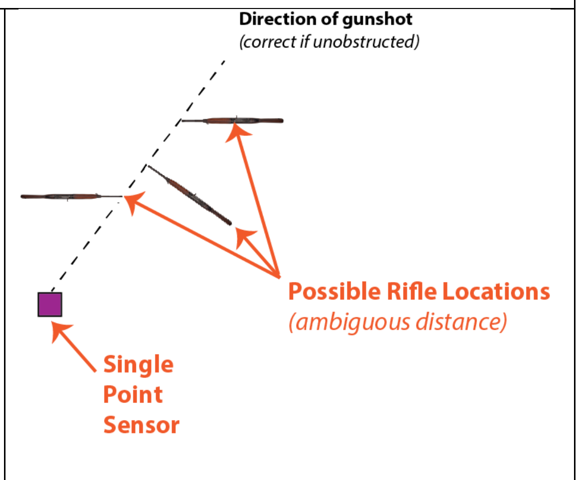
SINGLE POINT SENSORS

Single point sensors, sometimes called *proximity sensors*, generally require line-of-sight for accuracy and are commonly used to point individual video cameras located on top or right next to sensors towards the origin. They are quite sensitive to indirect path sound (sound which has refracted or bent around, *e.g.* buildings), echoes, and multipath (multiple sounds produced by overlapping echoes), because they do not commonly have the capacity to differentiate the "correct" direction from a potentially incorrect direction.

Single Point Sensors: Incorrect Direction and Range Ambiguities



Because sound bends around obstructions, single point sensors are highly vulnerable to indirect path errors (looking in the "wrong direction")



Because single point sensors cannot calculate range, they are highly vulnerable to distance ambiguities (looking in the right direction but "too far" or "too close")

Single point gunshot detection systems do not provide precise location calculations for the origin of gunfire, both because they lack the ability to correctly calculate range and because they can easily be misled by non-direct path propagation, as when sound bounces of buildings or other obstructions. In fact, many proximity sensors identify the location *of the sensor* and the direction (whether or not correct) from which they are triggered, thus requiring the end user to ascertain from the sensor's location and the relative direction what might have happened and where. It is for this reason that such sensors are commonly paired with cameras, and that their accuracy is usually limited to what the camera itself can see directly, if pointed in the direction.

A second shortcoming of proximity sensors is that they must necessarily be limited in the range at which they can detect gunfire. Even though a muzzle blast may be audible at distances of 1.5-2 miles, a proximity detector does not have the advantage of knowing how far away the origin of any given sound is. Thus it must listen for noises which "definitely sound like gunfire"—i.e., very loud noises produced relatively close by, because those are unlikely to be confusing. Different proximity sensors operate at different effective ranges, but generally speaking they are limited to radii of approximately 200-250 meters.

One advantage imparted by their very proximity, however, is speed of reaction. Although they can be fooled by sound coming from "the wrong direction," they will be activated relatively quickly: often within 1 second or less of the gun being fired.

DISTRIBUTED SENSOR ARRAYS

Unlike counter-sniper systems and proximity sensors, distributed sensor array networks do not trigger because a single sensor hears a noise. Instead, they require multiple sensors to hear a noise over a short period of time (a few seconds) and in a pattern mathematically consistent with that sound having originated at a single location. There are two general approaches: *multilateration based on time difference of arrival (TDoA)* and *triangulation (or generally multiangulation) based on angle of arrival (AoA).* ShotSpotter technology uses a patented combination of both TDoA and AoA. (It also detects and uses supersonic bullet *crack* noises *and adds them to the mathematical solution* when it is deployed in configurations likely to be shot at.)

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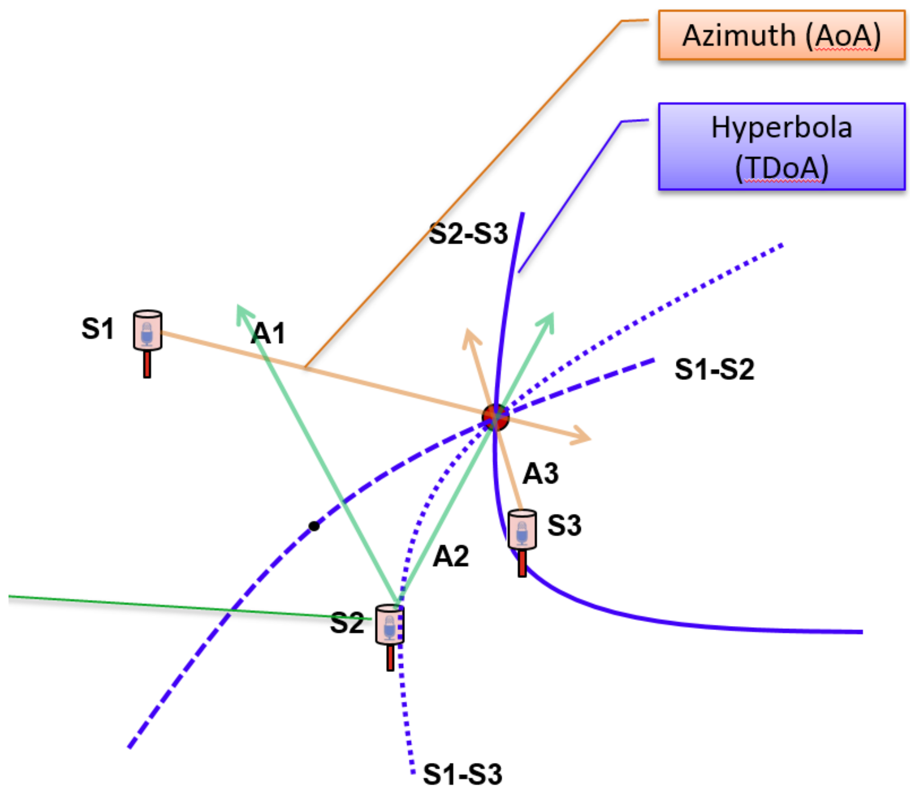
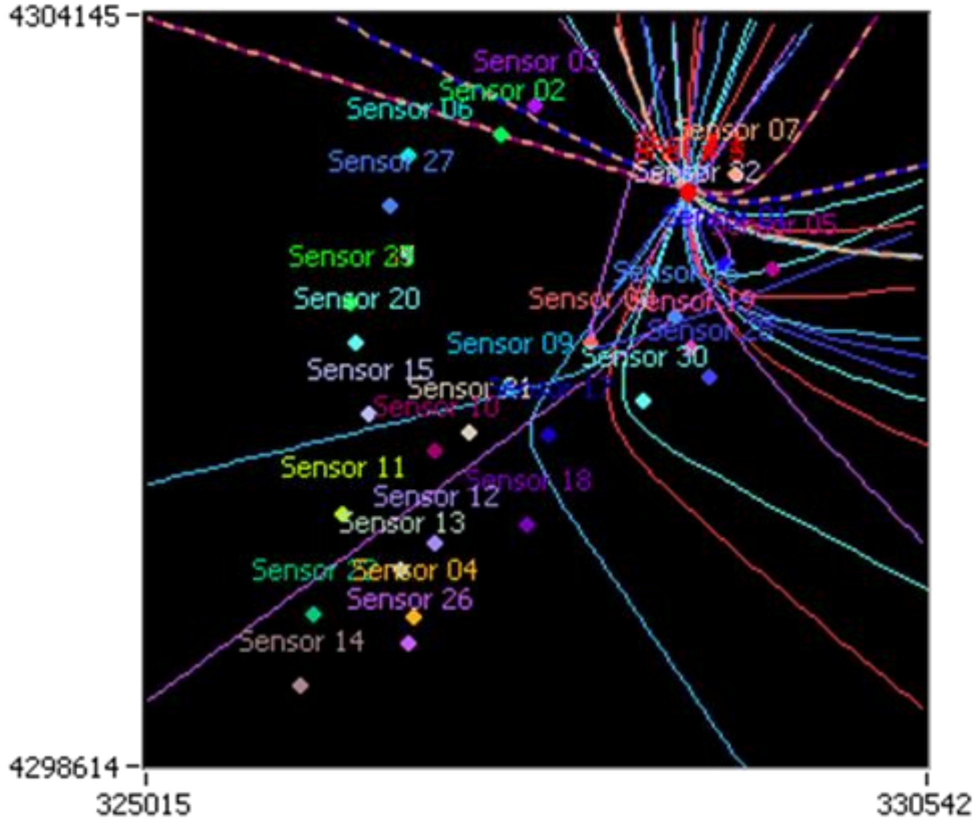


Through ShotSpotter Flex, SST is the only company in the world that uses a collaborative multi-sensor approach to detecting AND precisely locating gunfire on a wide area basis. Our aperture is the broadest in the market place. For example, many of our deployments cover 10 square miles or more of complex urban environments, where echoes, multipath, obstructions, and other complications are common. By combining TDoA and AoA techniques, ShotSpotter technology can locate gunfire on as few as two sensors (each providing one angle, or azimuth, and the pair providing a single hyperbolic time of arrival difference curve) or as many as 30 sensors (as commonly happens with large caliber long rifle weapons, such as 30-06 or .308, when fired from building rooftops or hilltops). The combination of physical perspectives (sensors at multiple distances and different angles) makes for complicated math, but beautiful solution graphs:



But what about false positives? We have addressed the false positive issue in three ways:

1) The physical distance travelled by a given sound is an important initial filter for all gunfire: gunfire travels far further than other impulsive sounds (except airborne fireworks). This "spatial filtering" technique underlies our first patent and has proven to be a reliable filter in every environment. (Impulsive sounds are the sounds of an *impulse* nature, such as explosions (fireworks, explosives), some specific types of construction (pile drivers), and, of course, gunfire.)
2) By an order of magnitude, we have the largest database of impulsive sounds (including gunfire) that we can leverage in regression testing to improve our classification recipes.
3) We operate the only 24x7x365 Incident Review Center in the world, where we apply human hears to the "last mile" classification process in real time to insure low false negatives and low false positives.

Is there a trade-off? As with all other approaches, there is. Sound travels at the speed of sound and no faster, and therefore it commonly takes 2-3 seconds for ShotSpotter sensors distributed over a large area to hear gunfire and for our servers to begin to locate it. For military counter-sniper use, such seconds matter, and therefore ShotSpotter's use in military contexts is limited to base and other large area protection. But in an urban environment, those 2-3 seconds provide ShotSpotter with unequalled accuracy and information, making the slight delay well worth it.

SO, WHAT GUNSHOT TECHNOLOGY WILL YOU USE?

The moral of the story is that all gunshot detection technologies are not created equal. A clear understanding of the use case: in the line of fire or across a broad area? Only supersonic with no false positives or any weapon and low false positives? Precise location in large non line-of-sight environments or line-of-sight in small, pre-determined areas? Pick your gunshot location technology as you would any other: the right tool for the right job makes all the difference.

ShotSpotter®

About SST

SST is the world leader in gunshot detection, delivering the proven solutions that help public safety, law enforcement and security forces across the globe respond to gunfire more efficiently, more effectively and more decisively. Its public safety technology solutions are focused on improving public and community safety by locating gunfire and other explosive events, and ultimately, helping reduce and prevent gun violence and improving intelligence-led policing and community policing initiatives. SST solutions protect cities and countries worldwide, enabling police and law enforcement to respond more quickly, safely, precisely and consistently to gunfire, and to aid proactive anti-crime strategies and operations. SST possesses a multitude of patents that are the result of nearly two decades of innovation in the area of acoustic gunshot location technology. Information about SST and ShotSpotter can be found at www.sst-inc.com or www.shotspotter.com. You can also follow ShotSpotter on Twitter, Facebook, LinkedIn and YouTube.

For more information on SST, please visit www.sst-inc.com or www.shotspotter.com.