Innovative multifrequency, multimode, modulated (MMM) sonic & ultrasonic vibrations for food-processing applications

MMM - Wideband Sonic and Ultrasonic Technology

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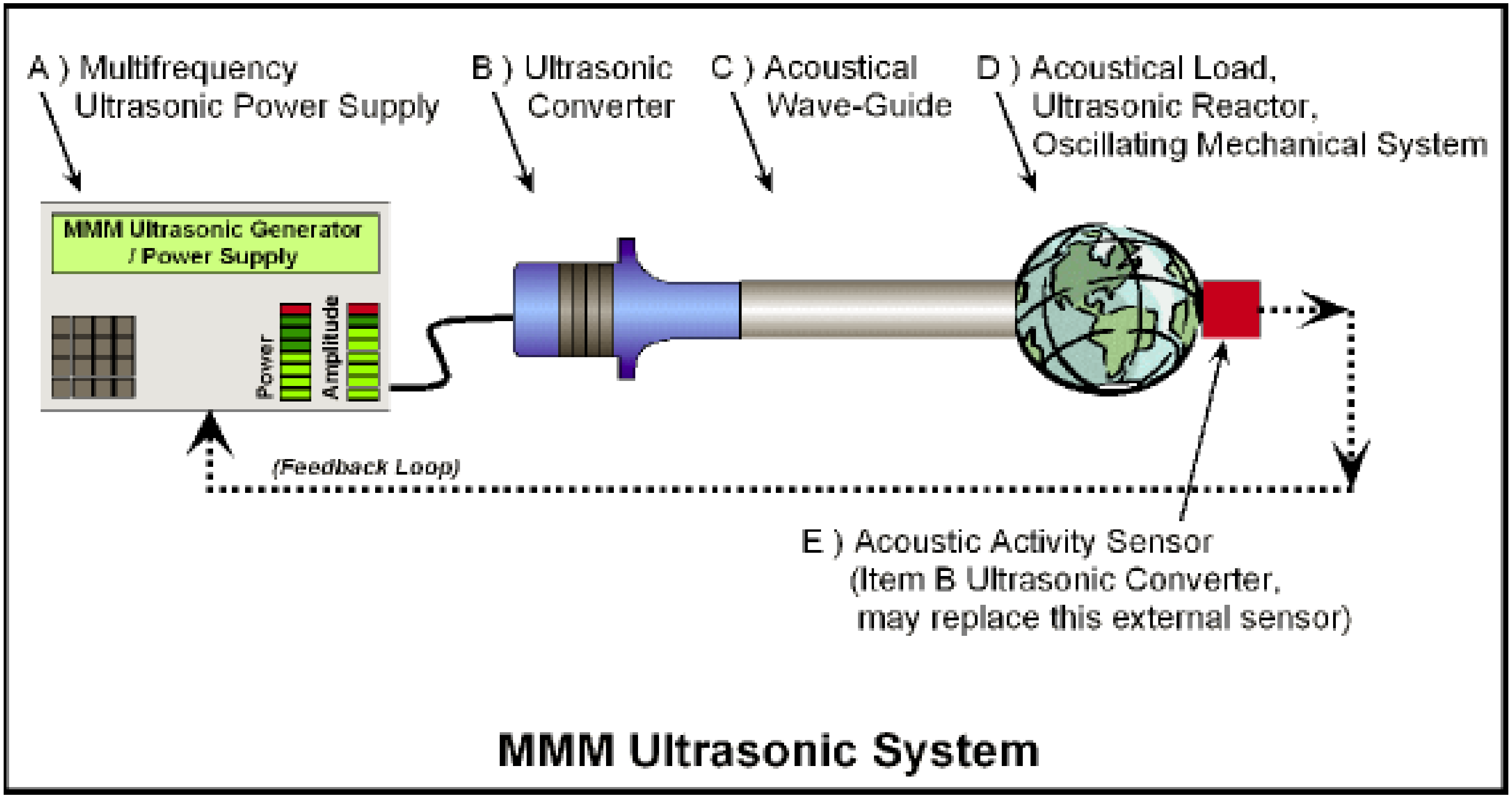
Until recently, traditional high intensity and fixed-frequency ultrasound has been applied in fields like cleaning, plastic welding, mixing and homogenization. However, new industrial ultrasound-related applications, such as sonochemistry, extractions, waste water treatment, etc., are becoming increasingly important, where fixed-frequency traditional ultrasonic systems are showing certain limitations.

The majority of the above-mentioned, old and new ultrasonic applications are presently based on fixed-frequency, well-tuned ultrasonic sources where a large number of design and matching parameters must be respected. These basic requirements significantly limit large scale and practical applications of the findings realized in laboratory-scale testing.

Extensive field tests conducted by experts in ultrasonics have demonstrated that in order to achieve a high efficiency, the ultrasonic systems must be well tuned to the load. Since most ultrasound units work inherently in non-stationary conditions, they have to, in theory, continuously adapt themselves to the load to maximize the efficiency, which is difficult to achieve with the fixed-frequency units. To meet this challenge, novel MMM signal processing techniques have been developed.

As a result of such an effort, the multifrequency, multimode, modulated (MMM) technology has become the first to succeed in applying "Wideband-frequency high-power ultrasonic agitation" to almost any existing ultrasonic equipment, regardless of its mass, load size and particular operating conditions. Furthermore, these new signal-processing techniques can be easily implemented without involving significant design modifications of existing systems.

In this presentation we will first give an overview of the signal processing techniques used by the "MMM technology" and show different novel and effective applications with an emphasis on food industry applications.



Block diagram of MMM ultrasonic System

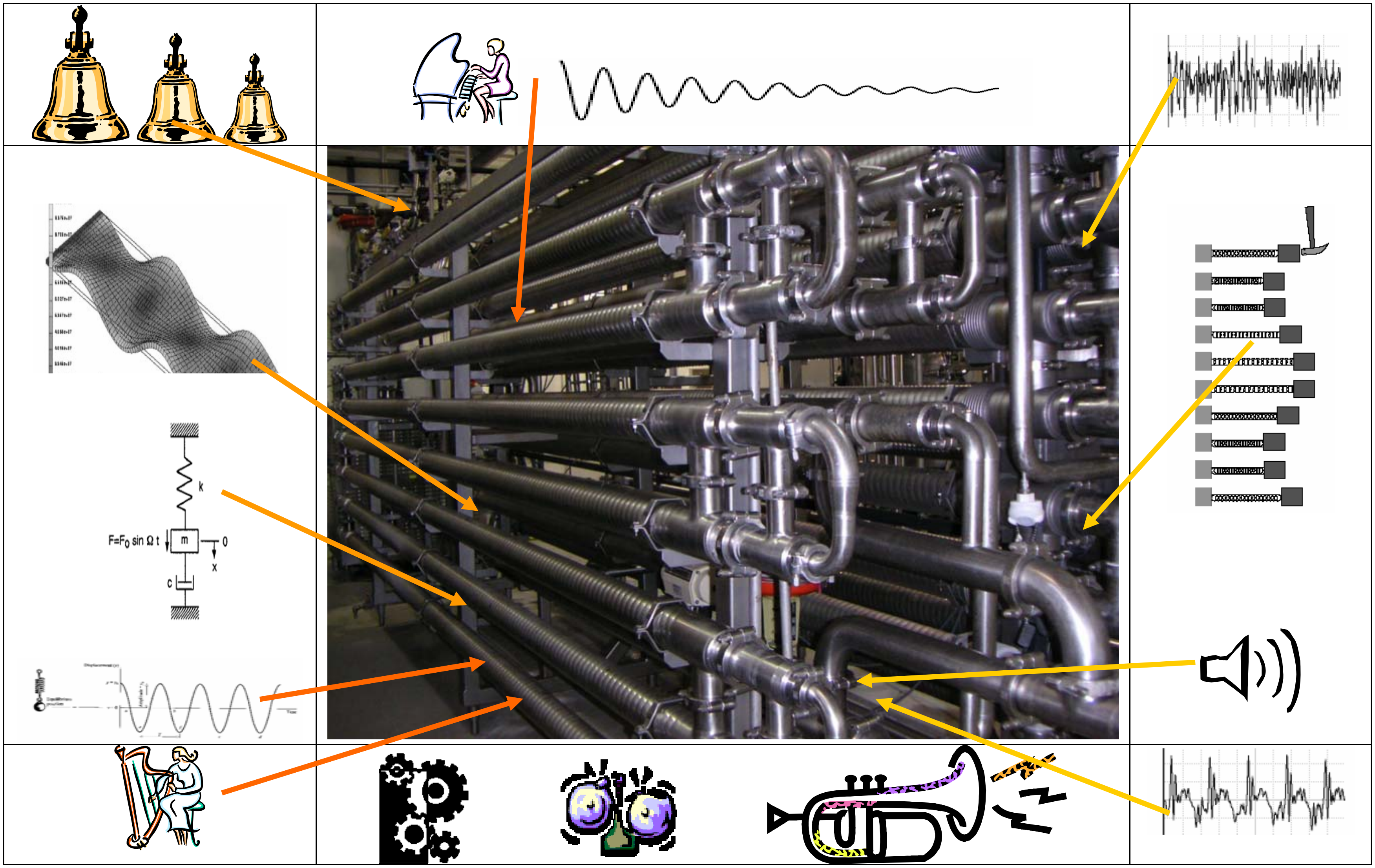
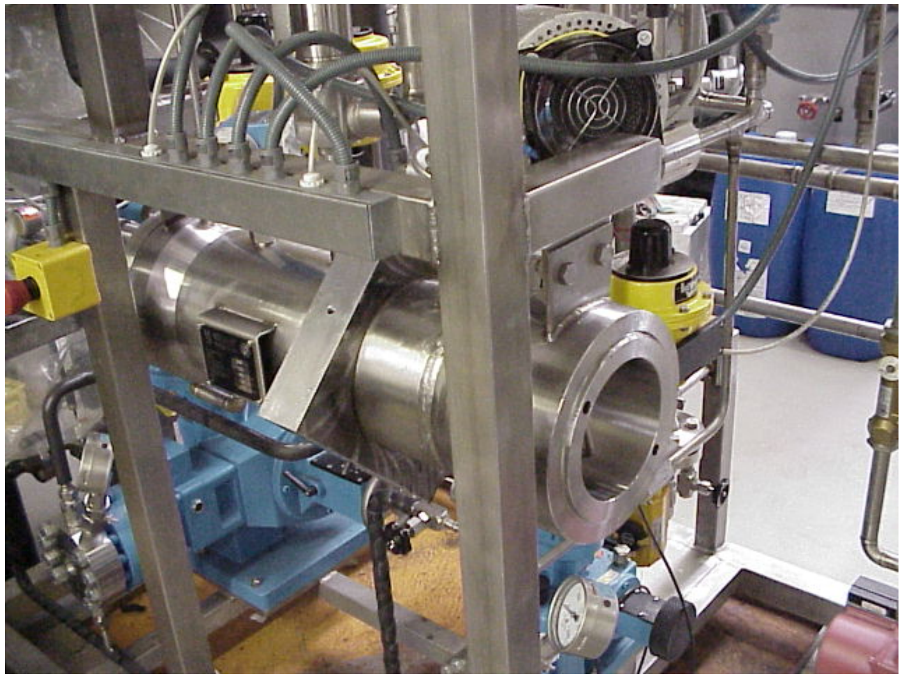
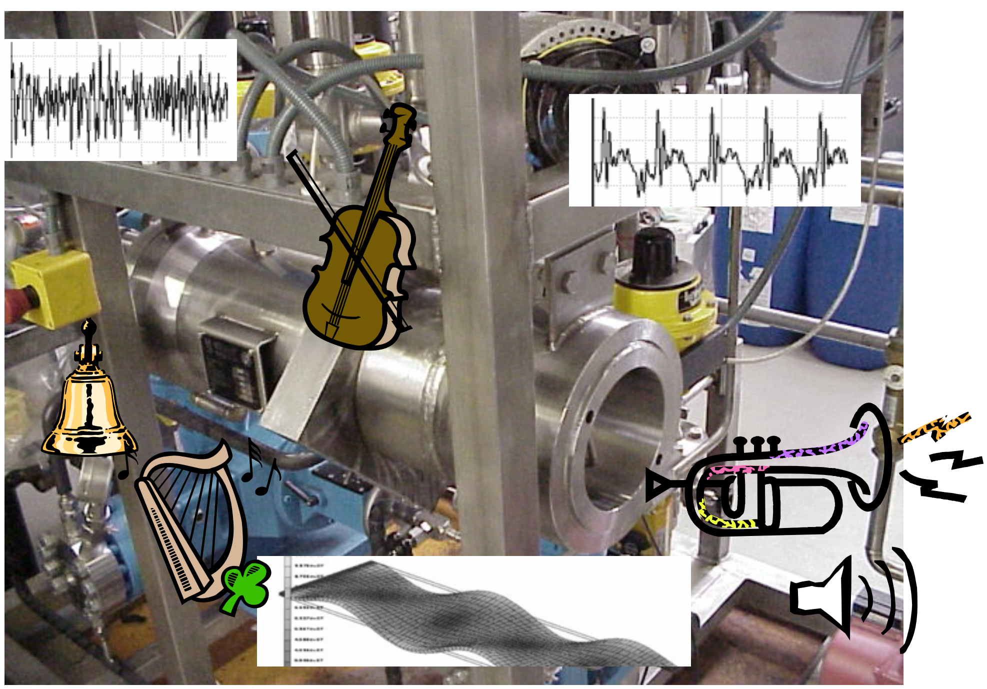


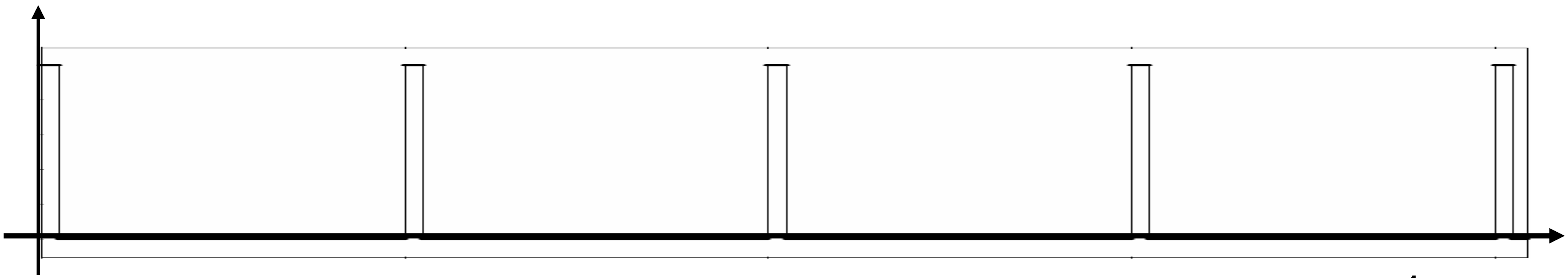
ILLUSTRATION OF DIFFERENT OSCILLATING MODES OF A COMPLEX MECHANICAL SYSTEM



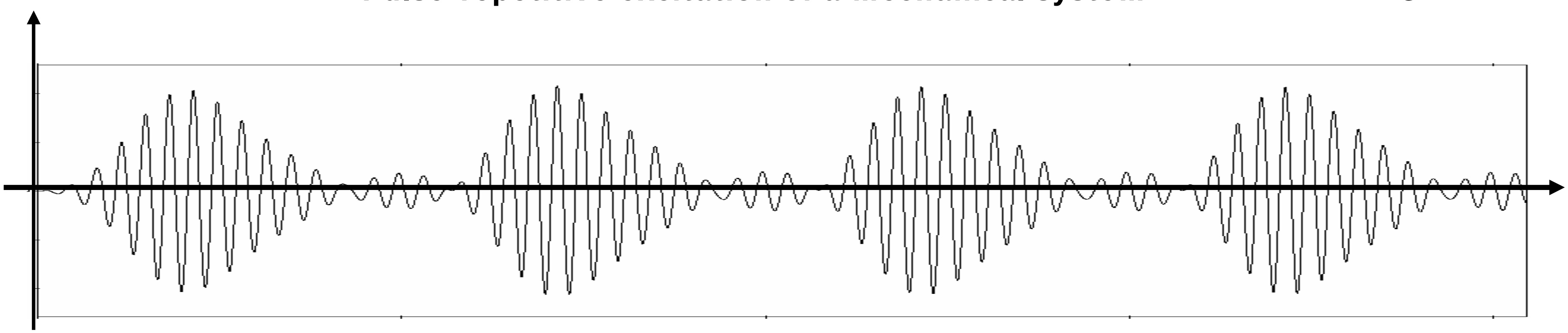
Complex mechanical system before MMM agitation



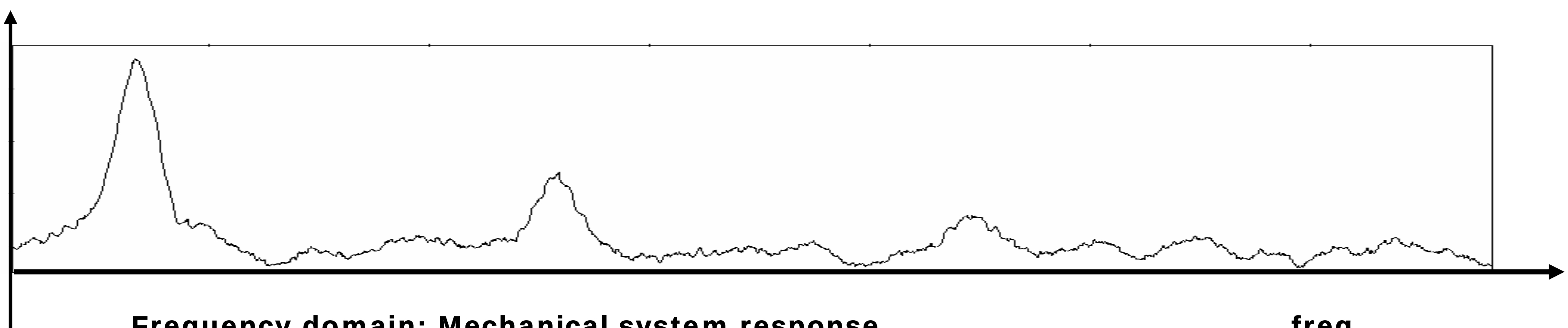
Complex mechanical system during MMM agitation



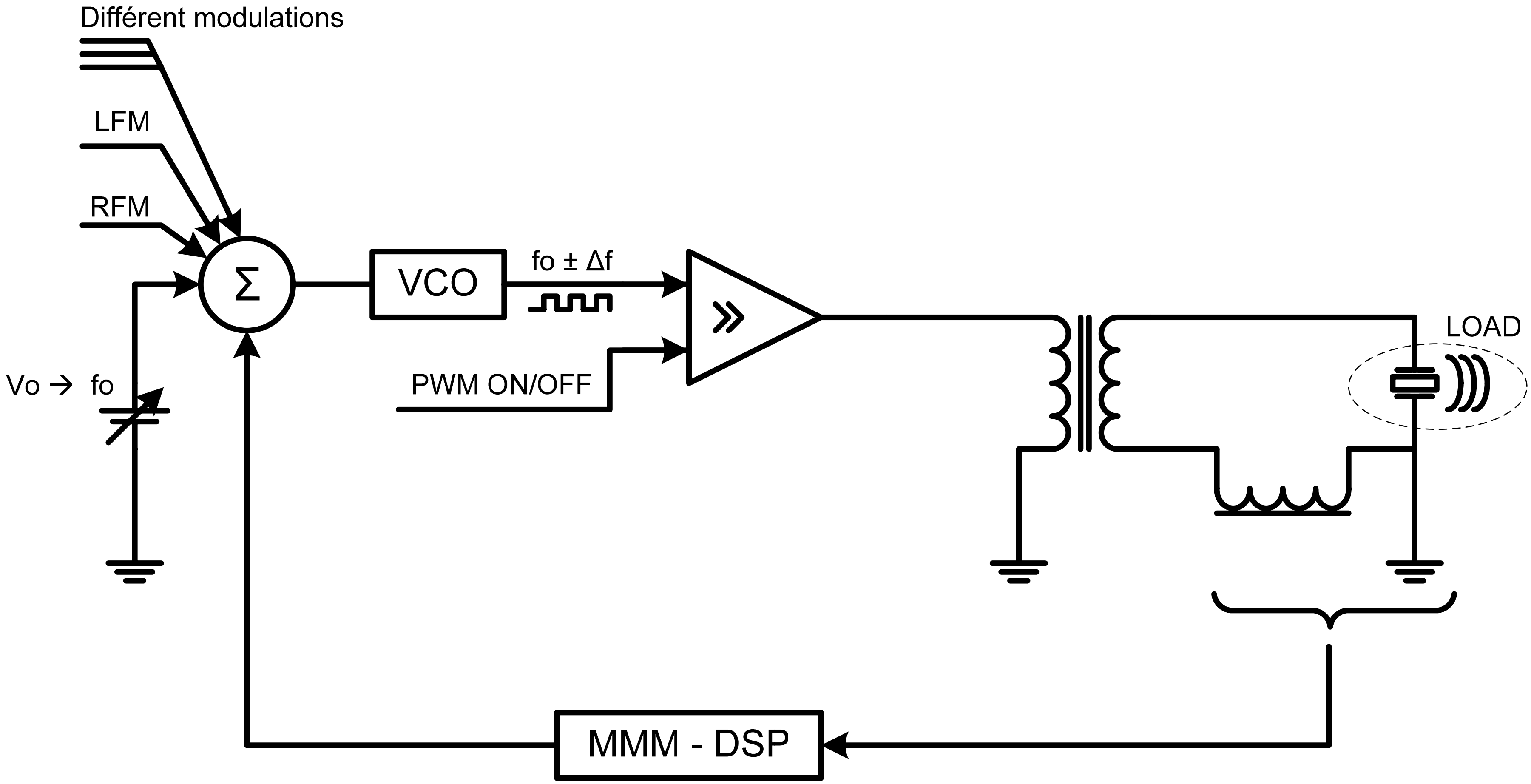
Pulse-repetitive excitation of a mechanical system



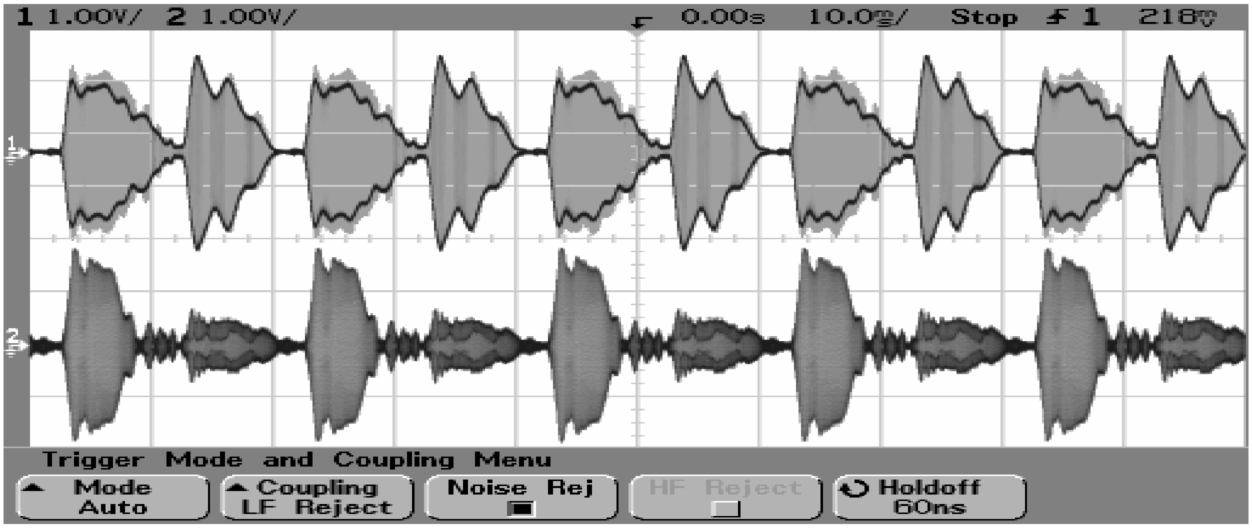
Time domain: Mechanical system response



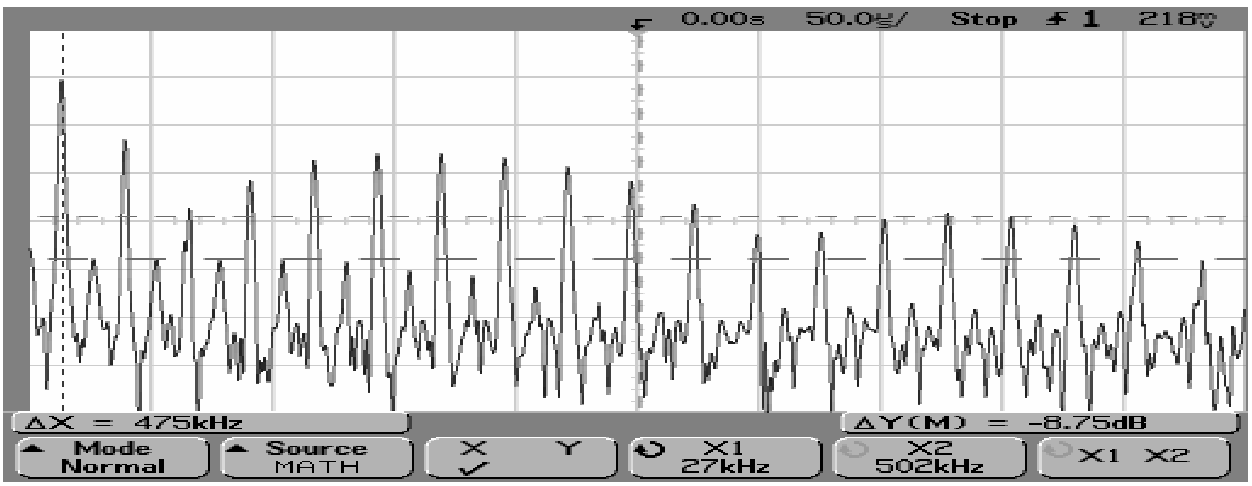
Frequency domain: Mechanical system response



MMM Power Supply Block Diagram
With dynamic, load-dependent frequency modulation
LFM - Low Frequency Modulation, **RFM** – Randomized Frequency Modulation



Examples of load voltage and current signals in a time domain



Example of a Frequency Domain of Load Oscillations

Basic Elements of MMM Systems
& How MMM Systems Operate

Ultrasonic systems based on our unique **MMM** (Multi-frequency, Multimode, Modulated) technology may be used as structural actuators capable of delivering high power sonic and ultrasonic energy to a large or small loads. MMM uses proprietary techniques to initiate ringing and relaxing multimode (wideband high and low frequency) mechanical oscillations in a mechanical body to produce pulse-repetitive, frequency, phase and amplitude modulated bulk-wave-excitation on that body.

***MMM** (**M**odulated, **M**ultimode, **M**ultifrequency) ultrasonic generators utilize a new and proprietary technology capable of stimulating wideband sonic and ultrasonic energy, ranging in frequency from infrasonic up to the MHz domain, that propagates through arbitrary shaped solid structures. Such industrial structures may include heavy and thick walled metal containers, pressurized reservoirs, very thick metal walled autoclaves, extruder heads, extruder chambers, mold tools, casting tools, large mixing probes, various solid mechanical structures, contained liquids, and ultrasonic cleaning systems.*

Every elastic mechanical system, body, or resonator that can oscillate usually has many vibrating modes as well as frequency harmonics and sub harmonics in the low and ultrasonic frequency domains. Many of these vibrating modes can be acoustically and/or mechanically coupled while others would stay relatively independent. The MMM technology can utilize these coupled modes by applying advanced Digital Signal Processing to create driving wave forms that synchronously excite many vibrating modes (harmonics and sub harmonics) of an acoustic load. This technique produces uniform and homogenous distribution of high-intensity acoustical activity to make the entire available vibrating domain acoustically active while eliminating the creation of potentially harmful and problematic stationary and standing waves structures. This is not the case for traditional ultrasonic systems operating at a stable frequency where creation of standing waves structures is the norm.

The MMM or multimode excitation techniques are very beneficial to many applications including liquid processing, fluid atomization, powders production, artificial aging of solids and liquids, accelerated stress relief, advanced ultrasonic cleaning, liquid metal treatment, surface coating, accelerated electrolysis, mixing and homogenizing of any fluid, waste water treatment, water sterilization, materials extrusion, wire drawing, improved molding and casting, and surface friction reduction to name a few.

***M**odulated, **M**ultimode, **M**ultifrequency sonic & ultrasonic vibrations can be excited in most any heavy-duty system by producing pulse-repetitive, phase, frequency and amplitude-modulated bulk-wave-excitation covering and sweeping an extremely wide frequency band. Every elastic mechanical system has many vibration modes, plus harmonics and sub harmonics, both in low and ultrasonic frequency domains. Many of these vibrating modes are acoustically and/or mechanically coupled, others are relatively independent. The MMM multimode sonic and ultrasonic excitation has the potential to synchronously excite many vibrating modes through the coupled harmonics and sub harmonics in solids and liquid containers to produce high intensity vibrations that are uniform and repeatable. Such sonic and ultrasonic driving creates uniform and homogenous distribution of acoustical activity on a surface and inside of the vibrating system, while avoiding the creation of stationary and standing waves, so that the whole vibrating system is fully agitated.*

Every MMM system consists of (see Fig. 1, below):

A) A Sweeping-Frequency, Adaptively Modulated Wave Form generated by an MMM Ultrasonic Power Supply (including all regulations, controls and protections);

B) High Power Ultrasonic Converter(s);

C) Acoustical Wave-Guide (metal bar, aluminum, titanium), which connects the ultrasonic transducer with an acoustic load, oscillating body, or resonator;

D) Acoustical Load (mechanical resonating body, sonoreactor, radiating ultrasonic tool, sonotrode, test specimen, vibrating tube, vibrating sphere, a mold, solid or fluid media, etc.);

E) Sensors of acoustical activity fixed on, in, or at the Acoustical Load (accelerometers, ultrasonic flux meters, cavitation detectors, laser vibrometer(s), etc.), which are creating regulation feedback between the Acoustical Load and Ultrasonic Power Supply. In most of cases the piezoelectric converter can function as the feedback element, avoiding installation of other vibrations sensors.

A strong mechanical coupling between the high-power Ultrasonic Converter (B) to the Acoustical Load (D) is realized using a metal bar as an Acoustic Wave-Guide (C).

The Ultrasonic Converter (B) is electrically connected to the Ultrasonic Multimode Generator Power Supply (A).

The Acoustic Activity Sensor (E) relays physical feedback (for the purpose of automatic process control) between the Acoustical Load (D) and Ultrasonic Power Supply (A).

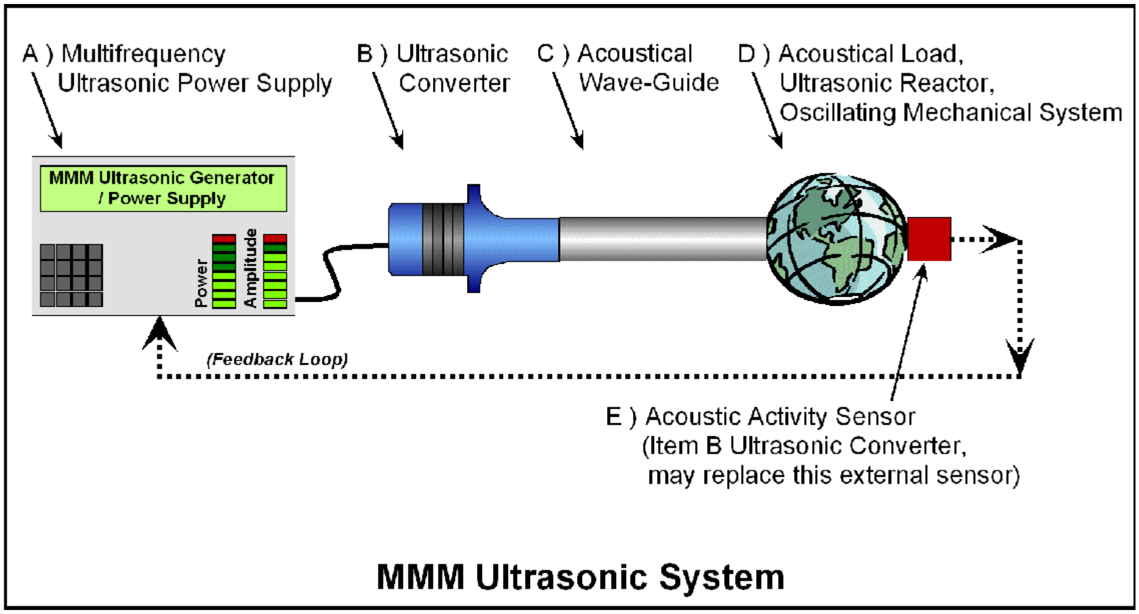


Fig. 1

MMM Generator Technology:

A new approach to Ultrasonic power supplies and systems

As depicted in Figure 1 above the Ultrasonic Converter (B), driven by Power Supply (A), is producing a sufficiently strong pulse-repetitive multifrequency train of mechanical oscillations or pulses. The Acoustical Load (D), driven by incoming frequency and amplitude modulated pulse-train starts producing its own vibration and transient response, oscillating in one or more of its natural vibration modes or harmonics. As the excitation changes, following the programmed pattern of the pulse train, the amplitude in these modes will undergo exponential decay while other modes are excited.

A simplified analogy is a single pulsed excitation of a metal bell that will continue oscillating (ringing) on several resonant frequencies for a long period following the initial pulse. How long each resonant mode will continue to oscillate after a pulse depends on the mechanical quality factor for that mode.

Every mechanical system (in this case the components B, C and D) has many resonant modes (axial, radial, bending, and torsional) and all of them have higher frequency harmonics. Some of the resonant modes are well separated and mutually isolated, some of them are separated on a frequency scale but acoustically coupled, and some will overlap each other over a frequency range and these will tend to couple particularly well.

Since the acoustical load (D) is connected to an ultrasonic converter (B) by an acoustical wave-guide (C), acoustical relaxing and ringing oscillations are traveling back and forth between the load (D) and ultrasonic converter (B), interfering mutually along a path of propagation. The best operating frequency of the ultrasonic converter (B) is normally found when the maximum traveling-wave amplitude is reached and when a relatively stable oscillating regime is found. The acoustical load (D) and ultrasonic converter (B) are creating a “Ping-Pong Acoustical-Echo System”, like two acoustical mirrors generating and reflecting waves between them. For easier conceptual visualization of this process we can also imagine multiple reflection of a laser beam between two optical mirrors. We should not forget that the ultrasonic converter (B) is initially creating a relatively low pulse frequency mechanical excitation, and that the back-and-forth traveling waves can have a much higher frequency.

In order to achieve optimal and automatic process control, it is necessary to install an amplitude sensor (E) of any convenient type (e.g. accelerometer, ultrasonic flux sensor) on the Acoustical Load (D). The sensor is connected by a feedback line to the control system of Ultrasonic Power Supply (A).

There is another important effect related to the ringing resonant system described above. Both the ultrasonic source (B) and its load (D) are presenting active (vibrating) acoustic elements, when the complete system starts resonating. The back-forth traveling-waves are being perpetually reflected between two oscillating acoustical mirrors, (B) and (D). An immanent (self-generated) multifrequency Doppler Effect (additional frequency shift, or frequency and phase modulation of traveling waves) is created, since acoustical mirrors, (B) and (D), cannot be considered as stable infinite-mass solid-plates. This self-generated and multifrequency Doppler Effect is able to initiate different acoustic effects in the load (D), for instance to excite several vibrating modes at the same time or successively, producing uniform amplitude distributions of acoustic waves in the acoustic load (D). For the same reasons, we also have permanent phase modulation of ultrasonic traveling waves since opposite-ends of the acoustic mirrors are also vibrating. We should strongly underline that the oscillating system described here is very different from the typical and traditional half-wave, ultrasonic resonating system, where the total axial length of the ultrasonic system consists of integer number of half-wavelengths. In the case of MMM systems we, generally speaking, do not care much about the specific ultrasonic system geometry and its axial (or any other) dimensions. Electronic multimode excitation continuously (and automatically) searches for the most convenient signal shapes in order to excite many vibration modes at the same time, and to make any mechanical system vibrate and resonate uniformly.

In addition to the effects described above, the ultrasonic power supply (A) is also able to produce variable frequency-sweeping oscillations around its central operating frequency (with a high sweep rate), and has an amplitude-modulated output signal (where the frequency of amplitude modulation follows sub harmonic low frequency vibrating modes). This way, the ultrasonic power supply (A) is also contributing to the multi-mode ringing response (and self-generated multifrequency Doppler effect) of an acoustical load (D). The ultrasonic system described here can drive an acoustic load (D) of almost any irregular shape and size. In operation, when the system oscillates we cannot find stable nodal zones, because they are permanently moving as a result of the specific signal modulations coming from the MMM Ultrasonic Power Supply (A)).

It is important to note that by exciting an acoustical load (D) we could produce relatively stable and stationary oscillations and resonant effects at certain frequency intervals, but also a dangerous and self-destructive system response could be generated at other frequencies. The choice of the central operating frequency, sweeping-frequency interval and ultrasonic signal amplitudes from the ultrasonic power supply (A) are critical elements to be carefully selected. Because of the complex mechanical nature of different acoustic loads (D), we must test carefully and find the best operating regimes of the ultrasonic system (B, C, D), starting with very low driving signals (i.e. with very low ultrasonic power). Therefore an initial test phase is required to select the best operating conditions, using a resistive attenuating dummy load in serial connection with the ultrasonic converter (A). This minimizes the acoustic power produced by the ultrasonic converter and can also dissipate accidental resonant power. When the best driving regime is found, we disconnect the dummy load and introduce full electrical power into ultrasonic converter.

The best operating ultrasonic regimes are those that produce very strong mechanical oscillations, or high and stable vibrating mechanical amplitudes, with moderate electric output power from the ultrasonic power supply. The second criterion is that thermal power dissipation on the total mechanical system continuously operating in air, with no additional system loading, is minimal. In other words, low thermal dissipation on the mechanical system (B, C, D) means that the ultrasonic power supply (A) is driving the ultrasonic converter (B) with limited current and sufficiently high voltage, delivering only the active or real power to a load. The multifrequency ultrasonic concept described here is a kind of “Maximum Active Power Tracking System”, which combines several PLL and PWM loops. The actual size and geometry of acoustical load are not directly and linearly proportional to delivered ultrasonic driving-power. Its possible that with very low input-ultrasonic-power a bulky mechanical system (B, C, D) can be very strongly driven (in air, so there is no additional load), if the proper oscillating regime is found.

Traditionally, in high power electronics, when driving complex impedance loads (like ultrasonic transducers) in resonance, a PLL (Phase Locked Loop) is related to a power control where load voltage and current have the same frequency. In order to maximize the Active Load Power we make zero phase difference between current and voltage signals controlling the driving voltage frequency. In modern Power Electronics we use Switch-Mode operating regimes for driving Half or Full Bridge, or some other output transistors configuration(s). The voltage shape on the output of the Power Bridge is square shaped (50% Duty Cycle), and current in the case of R/L/C resonant circuits as electrical loads always has a sinusoidal shape. Here we are dealing with a time domain current and voltage signals.

We can summarize the traditional PLL concept as:

Input values, Source CAUSE ⇒ (driving voltage)	Produced Response CONSEQUENCE/s (output current)	Regulation method for maximal Active Output Power
Square (or sine) shaped driving-voltage on the output Power Bridge	Sinusoidal output current	Control the driving-voltage frequency for minimal phase difference between output Load Voltage and Current signals.
Relatively Stable driving frequency (or resonant frequency)	Load Voltage and Current have the same frequency	Control the current and/or voltage amplitude/s for necessary Active Power Output (and to realize correct impedance matching)

The new MMM concept can be summarized as:

Input values, Source CAUSE ⇒ (driving voltage)	Produced Response CONSEQUENCE/s (output current)	Regulation method for maximal Active Output Power: The phase differences between the output HF current and voltage, on the output ferrite transformer, should be minimal in average.
Square shaped voltage on the output Power Bridge: PWM + Band Limited, Frequency Modulation (+ limited phase modulation in some applications)	Multi-mode or single sinusoidal output current (or ringing decay current) with Variable operating frequency + Harmonics	First PLL at resonant frequency: • To control the central operating frequency of a driving-voltage signal to produce Active Load Power much higher than its Reactive Power. • To realize the maximal input (LF) power factor (PF = cos(theta) = 1).
Stable central operating, driving frequency + band limited frequency modulation (+ limited phase modulation in some applications)	Stable mean operating (Load) frequency coupled with the driving-voltage central operating frequency, as well as with harmonics	• To make that complete power inverter/converter looks like a resistive load to the principal Main Supply AC power input. • To realize the maximal input (LF) power factor (PF = cos(theta) = 1).

Output transformer is "receiving" reflected harmonics (current and voltage components) from its load.	Particular frequency spectrum/s of a Load Voltage and Current could sometimes cover different frequency ranges.	Second PLL at modulating (sub-harmonic) frequency: • To control the modulating frequency in order to produce limited RMS output current and maximal Active Power (on the load). • To realize maximal input (LF) power factor (PF = cos(theta) = 1).

All over-power, over-voltage, over-current and over-temperature regulations, limitations and protections (pulse-by-pulse and in average) should be implemented. Safe operating components margins should be chosen sufficiently higher than in the cases of traditional, single frequency PLL systems.

The MMM concept is the most general case of Maximum Active Power Tracking and it covers the Traditional PLL concept. A number of variations of MMM concept are imaginable depending on resonant-load applications (like suppressing or stimulating certain operating frequencies or harmonics, implementing frequency sweeping, or randomized frequency and phase modulation/s etc.). Traditionally the PLL concept is applied to immediate load current and voltage signals, and in MMM we apply the similar concept to the immediate active load-power signal. In any case the principal objectives are to realize optimal and maximal active power transfer to the load, and that complete power system (in-average, time-vise) looks like resistive load to the main supply input, and this is exactly how MMM systems operate.

In conventional Ultrasonics technology the transducers and connected elements are designed to satisfy precise resonant conditions. To achieve maximum efficiency, all oscillating elements must be tuned to operate at the same resonant frequency. In contrast the patented MMM technology was developed to breakaway from this restrictive "tuned mode" by using advanced Digital Signal Processing (DSP) techniques to implement an intelligent feedback loop that allows adaptation to most any un-tuned, changing, or evolving mechanical system. Instead of optimizing acoustic elements to accept a specific resonant frequency operation, MMM systems use the intelligent DSP to adapt to the un-tuned load. The system continuously analyzes system-feedback and optimizes a complex shaped electrical driving signal customized to each specific oscillating structure.

To remain compatible with standard transducers the MMM generators use an adjustable primary resonant frequency as a

central carrier frequency that efficiently drives standard transducers in a modulated mode. The MMM driving oscillations are not only fixed or random, rather they follow a consistent and evolving pulse-repetitive pattern, where frequency, phase and amplitude are simultaneously modulated by the control system. The optimized modulations provide a highly efficient transfer of electrical to mechanical energy and prevent the creation of problematic stationary or standing waves as typically produced by traditional ultrasonic systems operating at a single frequency.

MMM systems offer a high level of control through regulation and programming of all vibration, frequency, and power parameters using either a handheld control panel or a Windows PC software interface. The system's fine control extends excellent repeatability and produces highly efficient active power that may range from below 100 W up to many kW. MMM technology can drive, with high efficiency, complex mechanical system up to a mass of several tons and consisting of arbitrary resonating elements.

Due to the flexible nature of the MMM technology, a wide range of new or improved applications are possible. For example applications requiring high temperatures represent a problem to conventional transducers that are extremely sensitive to heat. Since MMM systems are not restricted to specific tuned elements it is now possible to address high temperature applications through the use of extended acoustic wave-guides (e.g. 1 to 3 meters in length). An extended wave-guide puts the necessary physical distance between the heat sensitive transducer and the high temperature load. A long wave-guide also provides a convenient mounting point for cooling jackets that will draw away excessive heat and protect the transducer. Other fields of possible MMM Technology application are: Advanced Ultrasonic Cleaning, Material Processing, Sonochemistry, Liquid Metals and Plastics treatment, Casting, Molding, Injection, Ultrasonically assisted sintering, Liquids Atomization, Liquids Mixing and Homogenization, Materials Testing, Accelerated Aging, and Stress Release.

Example Ultrasonic Applications That Can Benefit From MMM Systems

1. Ultrasonic liquid processing
   a. mixing and homogenization
   b. atomization, fine spray production
   c. surface spray coating
   d. metal powders production and surface coating with powders
2. Sonochemical reactors
3. Water sterilization
4. Heavy duty ultrasonic cleaning
5. Pulped paper activation (paper production technology)
6. Liquid degassing, or liquid gasifying (depending of how sonotrode is introduced in liquid)
7. De-polymerization (recycling in a very high intensity ultrasound)
8. Accelerated polymerization or solidification (adhesives, plastics…)
9. High intensity atomizers (cold spay and vapor sources). Metal atomizers.
10. Profound surface hardening, impregnation and coating
    a. surface hardening (implementation of hard particles)
    b. capillary surface sealing
    c. impregnation of aluminum oxide after aluminum anodizing
    d. surface transformation, activation, protection
11. Material aging and stress release on cold
    a. Shock testing. 3-D random excitation
12. Complex vibration testing (NDT, Structural defects detection, Acoustic noise…)
    a. accelerated 3-dimensional vibration test in liquids
    b. leakage and sealing test
    c. structural stability testing of Solids
    d. unscrewing bolts testing
13. Post-thermal treatment of hardened steels (cold ultrasonic treatment)
    a. elimination of oxides and ceramic composites from a surface
    b. profound surface cleaning

c. residual stress release, artificial aging, mechanical stabilization

14. Ultrasonic replacement for thermal treatment. Accelerated thermal treatment of metal and ceramic parts in extremely high intensity ultrasonic field in liquids.

15. Surface etching

a. abrasive and liquid treatment

b. active liquids (slightly aggressive)

c. combination of active liquids and abrasives

16. Surface transformation and polishing

a. combination of abrasives and active liquid solutions

b. electro-polishing and ultrasonic treatment

17. Extrusion (of plastics and metals) assisted by ultrasonic vibrations

a. special ultrasonic transducers in a direct contact with extruder

18. Founding and casting (of metals and plastics) assisted by ultrasound

a. vacuum casting, homogenization, degassing

b. micro-crystallization, alloying, mixing of different liquid masses

19. Adhesive testing

a. aging test

b. accelerated mechanical resistance testing

c. accelerated moisture and humidity testing

20. Corrosion testing

a. in different liquids

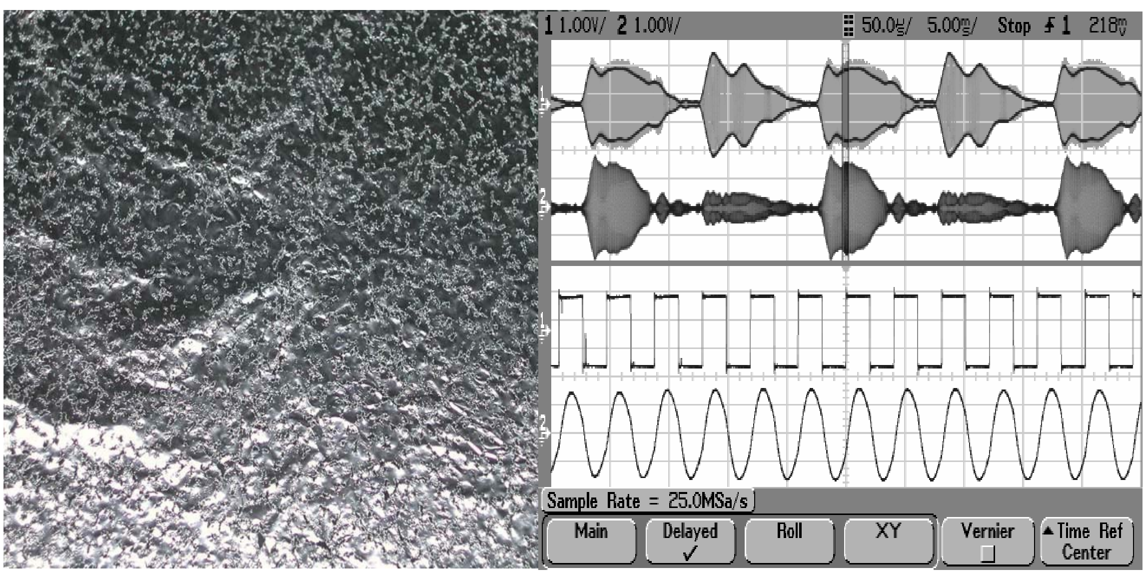
- **in corrosive liquid, vapor phase**

MMM SONIC & ULTRASONIC CLEANING & LIQUID PROCESSING

MMM Technology: Multifrequency, Multimode, Modulated Sonic & Ultrasonic Technology

No other manufacturer has yet achieved and matched MMM exciting standards in precision cleaning. MMM is not only more efficient and effective than any other ultrasonic cleaning technology, it is UNIQUE.

- **Seeing is the believing! Try the aluminum foil test for yourself! Place the foil sample into our ultrasonic bath and hold the foil for approx. 5 -10 seconds and you'll discover why there's simply no comparison with any other conventional ultrasonic cleaning machine.**



Left: Perfectly, uniformly perforated aluminum foil, after 5 to 10 seconds of exposure to MMM ultrasonic vibrations in an ultrasonic cleaner. Frequency Range: From Hz to MHz; From Infrasonic to Supersonic. Right: Load current and voltage shapes (modulated and carrier).

- **Superior and deep penetration, independent of water levels.**
- **Reliability with extra power spread throughout the bath.**
- **Even distribution of ultrasonic energy throughout the liquid gives uniform and thorough cleaning of the surface without the risk of damage to fine parts and sensitive instrument.**
- **Extremely efficient electronics and transducer coupling to ultrasonic bath (overall approx. 95% efficiency) eliminates or reduces the additional need for heating.**
- **Spatial distribution of ultrasonic activity inside of a cleaning liquid is homogenous (no dead zones, no standing waves, fast and large frequency sweeping, broadband spectrum, complex modulation).**
- **Cleaning solvents, detergents and additives can be significantly reduced, or even eliminated because of the very high cleaning activity of the acoustic broadband spectrum.**
- **Cleaning time can be several times shorter comparing to traditional ultrasonic cleaning technology.**
- **Fast liquid conditioning and degassing because of very large regulating zone between maximal and average ultrasonic power and because of the ability to switch instantaneously between acoustic spectrums.**
- **Smooth Ultrasonic, PWM-power regulation from 1% to 100%. Ultrasonic energy can be easily adjusted in order to clean very fine and sensitive parts**

Please visit our website for more details, or contact us directly with any inquiries:

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(54) **Multifrequency ultrasonic structural actuators**

(57) The propagation of ultrasonic energy in arbitrary shaped solid structures (D), heavy and very-thick-walls metal containers, pressurized reservoirs, very-thick metal-walls autoclaves, in different mechanical oscillating structures and systems,... is realized using a novel ultrasonic structural, multifrequency actuator (including very particular multifrequency ultrasonic power supply, also the subject of this invention), able to initiate ringing and relaxing, multimode mechanical oscillations (harmonics and sub harmonics) in any heavy-duty, bulky and rigid system, producing pulse-repetitive, phase, frequency and amplitude-modulated bulk-wave-excitation (covering and sweeping extremely large frequency area). Such ultrasonic driving is creating uniform and homogenous distribution of acoustical activity on a surface and inside of the vibrating system, while avoiding creation of stationary and standing waves structure, making that the complete vibrating system is fully agitated. Multifrequency ultrasonic structural actuator is ideal for agitating arbitrary distant and arbitrary shaped liquid and solid masses placed in different open or pressurized vessels, containers, autoclaves, reservoirs and pipes, transferring vibrations via wave-guide solid rod fixed betweem the transducer and a loading mass (where loading mass presents an oscillating body, and/or oscillating vessel, autoclave, container...). This invention presents an extension and continuation of the previous patent, originating from the same Author/Inventor (see 1 060 789 A1), explaining the additional aspects of particular electronics necessary to drive ultrasonic transducers in a multifrequency and multi-mode oscillating regime/s, while keeping high efficiency of electric and ultrasonic energy transfer and/or transformation. Fields o f possible applications related to this invention are: Ultrasonic Cleaning, Welding,Material Processing, Sonochemistry, Liquid Metals treatment, Atomization, Materials Testing, Aging and Stress Release, Homogenization, Process Industry, etc.

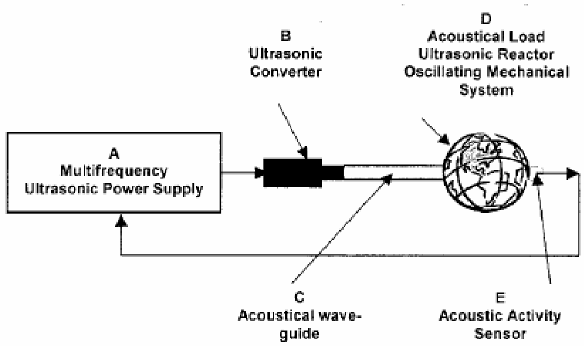

Fig. 1 Block Diagram of a Multifrequency Structural Actuator

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