IMPULSE ALIGNMENT OF LOUDSPEAKERS AND MICROPHONES

by Tom Lubin and Don Pearson

PART ONE

When the earliest recordings were done there was little if any attention given to the acoustic phase or electrical polarity of the mechancial devices used to record and reproduce sound. Phase and polarity have little significance as long as only one microphone picks up the sound and one speaker plays. When recording left the experimental stage it became possible to mix together more than one microphone. This allowed for better control and balance among the instruments.

With advancements in technology, multi-microphone techniques developed. In not too long a time the recording engineer discovered that occasionally when the outputs of two microphones were combined their summed output level would be less than the output of each one separately. In some cases the cancellation was almost complete and affected all frequencies. In other instances cancellation occurred at certain frequencies only. Thus, electrical polarity and acoustic phase cancellation became observable problems with the increased use of multi-microphone techniques.

Similar problems existed when monophonic reproduction became stereo. The electrical phase relationship between the two speakers had to be the same. Multi-speaker systems have made the problem of polarity and phase even more critical as each element must be connected correctly. This may not necessarily mean that the electrical polarity be the same for all of the speakers. Acoustic phase cancellation occurs in multi-speaker systems as well, but not until very recently had it been acknowledged, possibly because it is less distinct than the cancellation which occurs when two or more microphones which are picking up the same sound are electrically combined. When our ears mix the signal from two or more speakers what we hear is influenced by the acoustics of the room, and the fact is we have ears instead of amplifiers doing the combining. Before describing a technique for evaluating phase, polarity and a number of other aspects of speaker system analysis, an explanation of polarity and phase should be given.

Polarity and phase are relative terms. Polarity refers to the property that physical quantities have of being greater or less than some reference value that we may arbitrarily designate as the point of reference or "zero." A point on a line may be thought of as being closer to an observer than another point thought of as a reference or farther away than that same reference point. Its position may be described as corresponding to a positive number in one case and to a negative number in another. A voltage may be thought of as being positive with respect to one reference potential and another voltage may be observed to be negative referenced to that same potential. Both voltages may be either positive or negative when referenced to the potential of the earth which, by the way, may not be resting at zero with respect to the universe.

Phase is a term that is implicitly linked to an ongoing time sequence of two or more series of events as observed relative to some common reference point in time. Events that are considered to be "in phase" are events that have their time sequences of increase and decrease occurring simultaneously. Events that are said to be "out of phase" occur in such a way that their increasing and decreasing sequences do not occur precisely together. The measure of the difference in phase is always expressed as a time relation, be it in terms of actual seconds, minutes, hours, etc., or as relative time in terms of increments or fractions of complete cycles of events, such as in units of degrees or radians. It is clear that two or more events may be precisely in ***phase*** with one another while being of either positive or negative polarity. Phase and polarity are related although one is not precisely identical to the other.

Electrical Polarity

Electrical polarity in a speaker is defined in terms of whether the speaker ***condenses*** or ***rarifies*** when it is energized by a

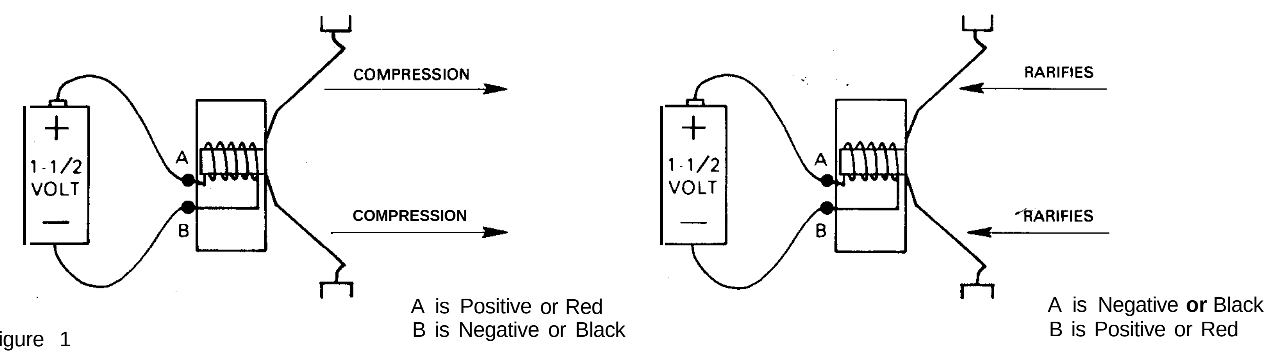

Figure 1

positive pulse (Figure 1). Most manufacturers indicate with colored binding posts a difference between the speaker terminals. Unfortunately, inconsistant or incorrect polarity distinction is quite common, partly due to erratic quality control and the fact that some manufacturers wire their elements opposite to other manufacturers. The polarity of a woofer can be easily determined with a 1% volt battery. When the speaker leads touch the battery terminal, the cone will move in or out. If it moves out the terminal touching the positive side of the battery is positive in that it condenses the air. If the cone moves in then the terminals are reversed. The negative side of the battery is connected to the positive side of the speaker causing the cone to rarify.

Unfortunately, high-frequency speaker elements cannot be checked in this manner because the diaphram movement is so slight and is usually difficult to see since it is usually deep inside the horn.

Crossovers

In systems that use a number of full range speakers the phase should be the same for all units, however with the use of specialized speakers which reproduce only one area of the audio range, a crossover of some type must be introduced into the audio path. Almost all crossovers introduce some degree of phase shift in order to achieve a sufficiently steep roll off to both sides of the pass band.

For example, let's say we have a three-way network that crosses at 500 Hz and 2,000 Hz. At 500 Hz both the woofer and the mid-range are reproducing a signal that is 3 dB down from their respective full power passband levels. At that frequency both of them are theoretically reproducing an equal acoustic power level, so their on-axis response will sum by 3 dB. If they sum by 3 dB, and they are both down by 3 dB at the crossover point then the system should have a flat response providing all the phases are correct. But what is the correct phase? That's the crunch.

The degree of phase rotation introduced by the crossover will vary from unit-to-unit, but can be considerable. Almost always the phase of the roll-off/roll-on of adjacent bands will rotate in opposite directions at the crossover frequency. The net result will have the mid-range acoustically out of phase with the woofer at the crossover frequency because of the phase shift in the crossover.

In order for the entire system to be acoustically in phase at the crossover point, it may be necessary to alternate the speaker polarity of each adjacent band. Manufacturers of crossovers fail to meet this need as phase reversal switches are seldom provided. The fact that the speakers of two adjacent passbands are electrically out of phase is of no consequence since it is only at the crossover points that they share common information, and must be acoustically in phase with one another.

Finally, a speaker is theoretically a single point source of sound. With the addition of each speaker to a system, the

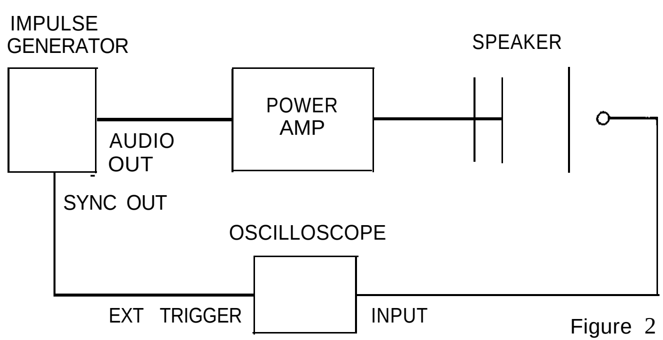

Figure 2

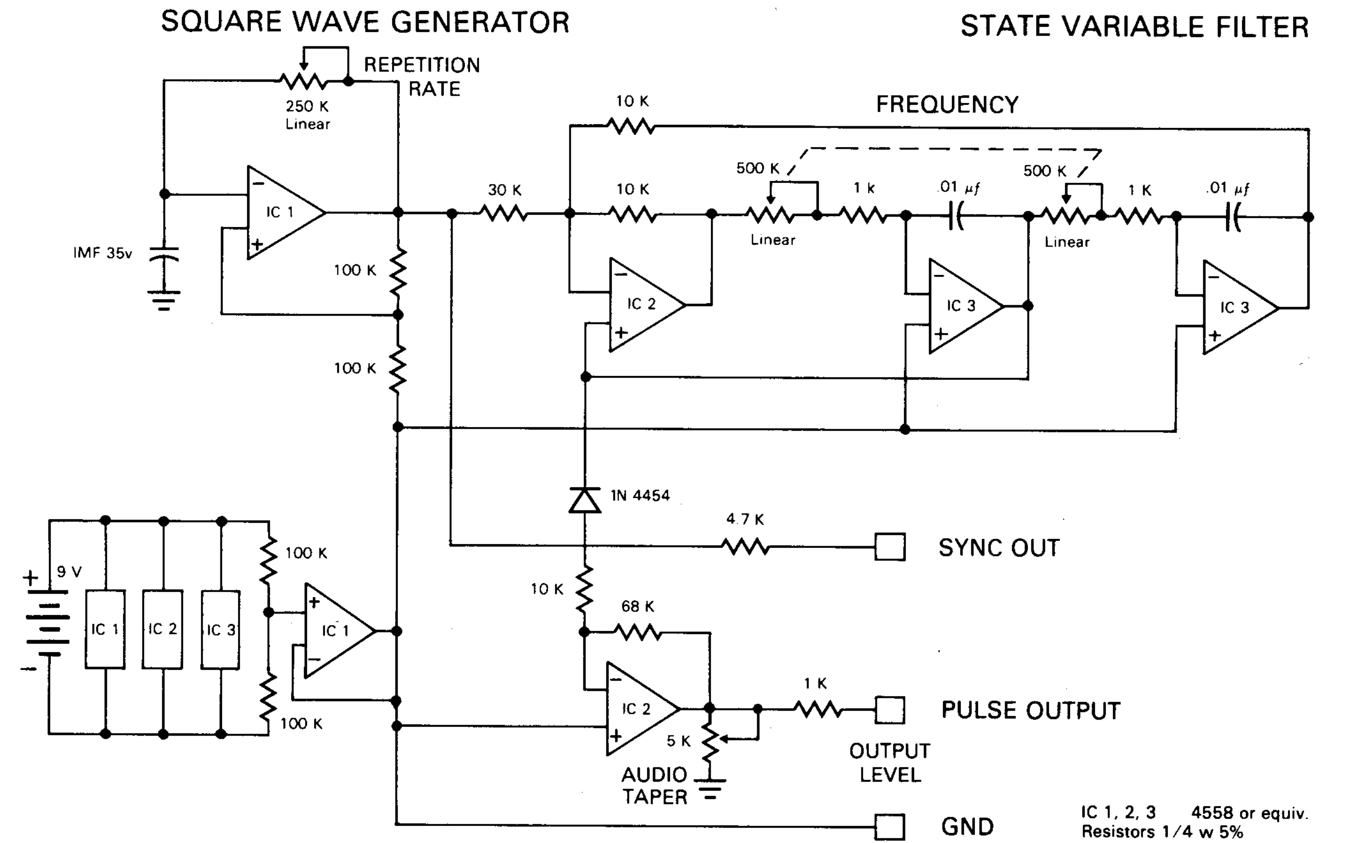
SQUARE WAVE GENERATOR
STATE VARIABLE FILTER
REPETITION RATE
250 K Linear
FREQUENCY
10 K
500 K
1 k
.01 μf
500 K
1 K
.01 μf
30 K
10 K
Linear
Linear
IC 1
IMF 35v
100 K
IC 2
IC 3
IC 3
100 K
1N 4454
4.7 K
SYNC OUT
9 V
IC 1
IC 2
IC 3
100 K
IC 1
100 K
10 K
68 K
IC 2
1 K
PULSE OUTPUT
5 K
AUDIO TAPER
OUTPUT LEVEL
GND
IC 1, 2, 3 4558 or equiv.
Resistors 1/4 w 5%

Figure 3

number of point sources increases. If each point source is not exactly the same distance from the listener then what occurs is an auditory double image. This is particularly apparent at the crossover points. Basically, a single moment in time is generated by all the speakers at the same instant, but arrives at the listener at a number of different times. This causes the intelligibility of the entire system to be lowered.

Clarity is also affected by “out of band” distortion generated by the enclosure. If a cabinet is not adequately braced it will resonate or “ring” substantially. The box can put out almost as much sound as the speaker itself. Likewise metal horns, if not properly dampened, can contribute undesired vibrations.

The solution to many of these problems is fairly simple once an accurate method of measurement is provided. Operating as an independent testing service, Don Pearson and Gary Leo, of *Ultra Sound,* located in Larkspur, California, has developed such a system. With the aid of their computer they provide information on all of the previously mentioned problems as well as a number of other acoustic and electronic parameters relating to the sound equipment used by their clients. A permanent record is kept, in the form of a printout, for these clients who number several very prominent sound reinforcement companies.

A Simpler Method

Ultra Sound has allowed the publication of a simple circuit which when constructed can be used with a microphone and an oscilloscope to measure polarity, phase of a wave, and ringing. Figure 2 is the schematic of an “impulse” generator with variable frequency and repetition rate. Figure 3 illustrates the proper hook-up of the system. Any oscilloscope with an external trigger will do as will any conventional microphone. Ultra Sound prefers a Nakamichi CM 300 fitted with a CP 3 super-omni ½-inch element. The microphone should be placed a few feet from the speaker (the larger the speaker, the greater the distance between the mike and speaker). The speaker’s impulse output should be loud enough to mask any room noise.

Before testing can be done, the polarity of the microphone to be used as the standard must be determined. First connect the

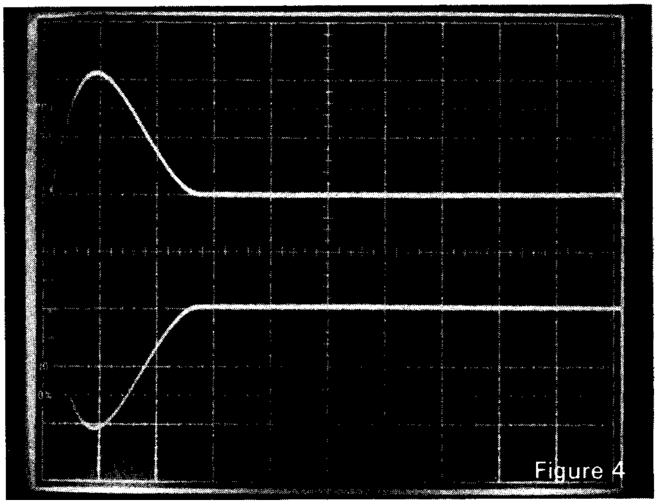
Figure 4

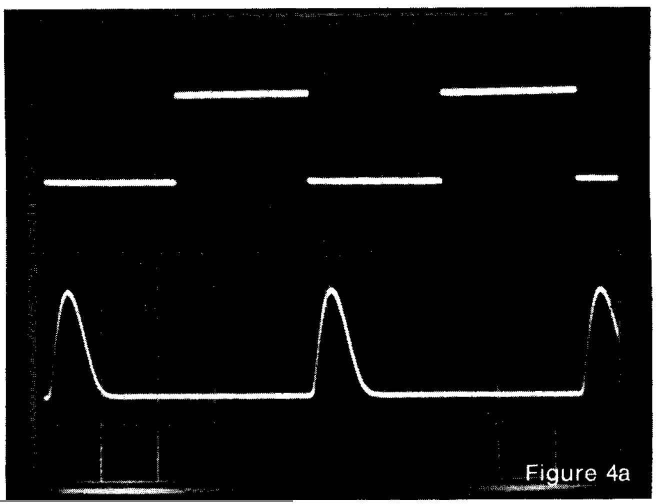
Figure 4a

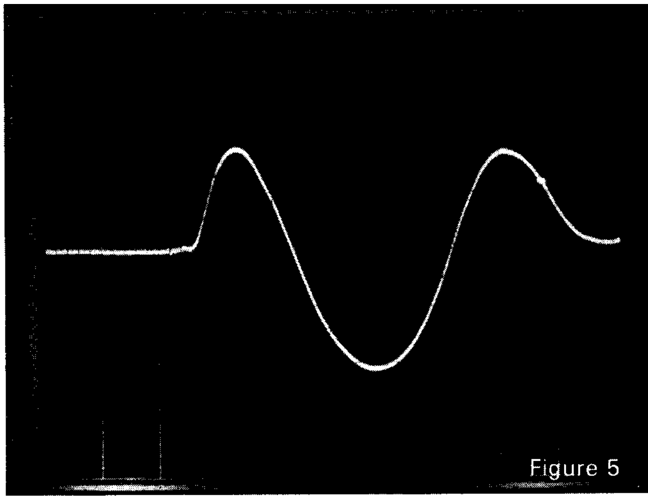
Figure 5

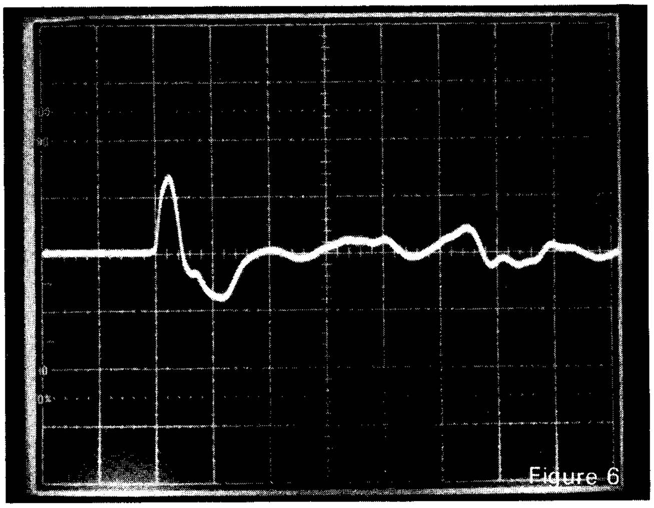
Figure 6

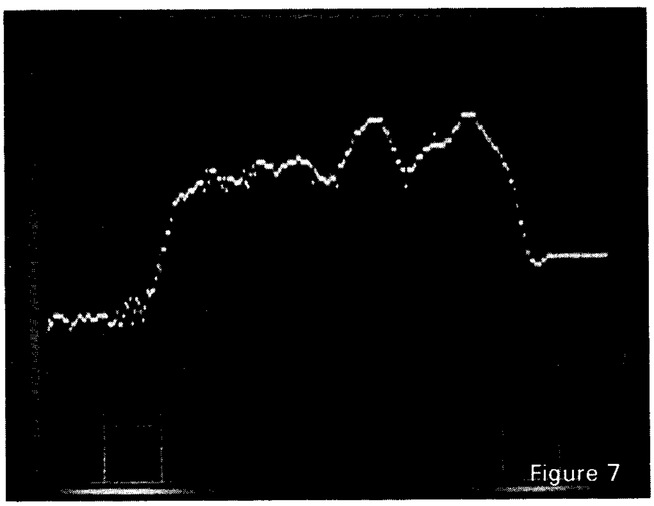
Figure 7

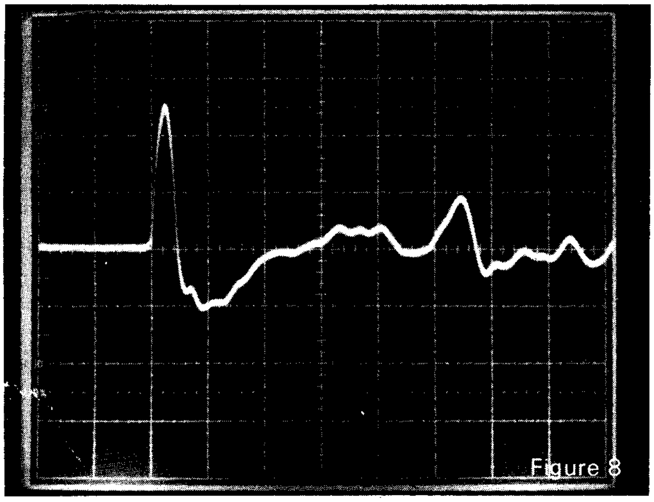

Figure 8

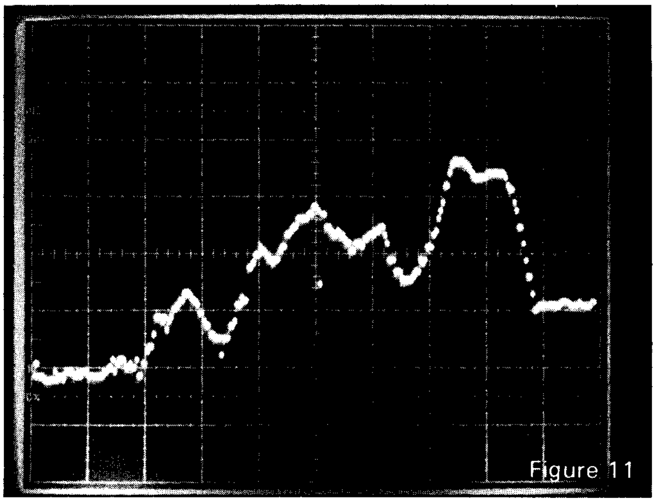

Figure 11

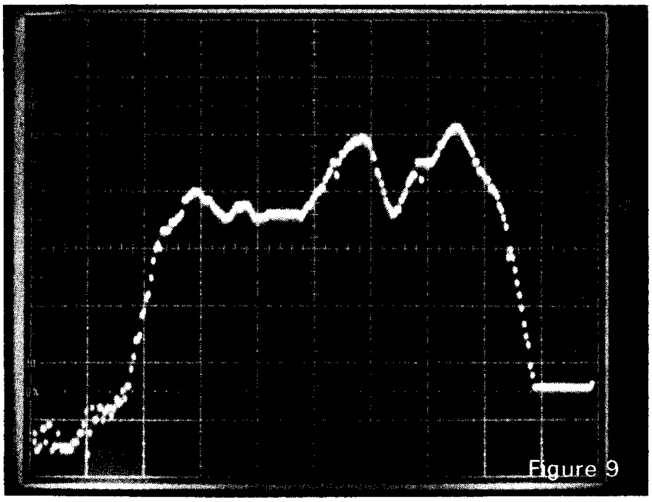

Figure 9

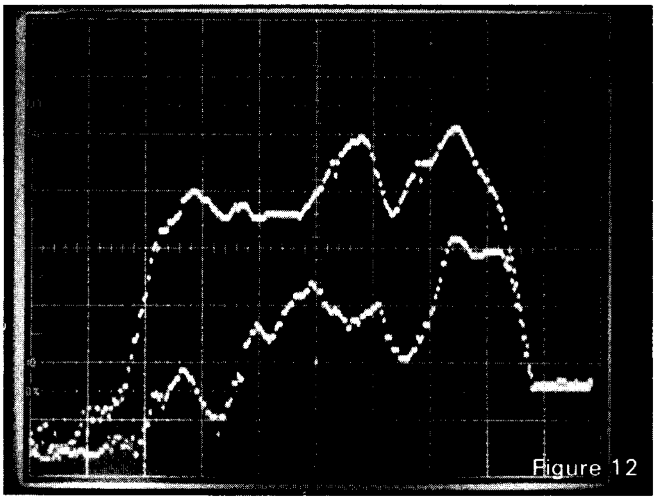

Figure 12

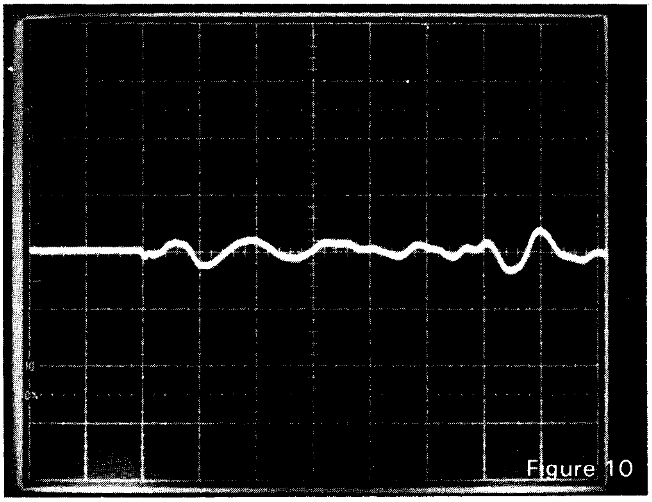

Figure 10

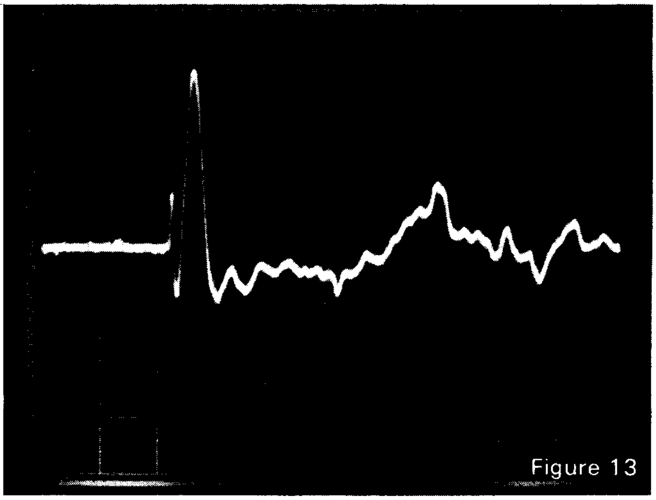

Figure 13

output arriving at the speaker to the input of the scope and observe whether the waveform is positive or negative going (Figure 4). Reconnect the speaker to the amp and connect the microphone to the oscilloscope and again observe the polarity. While observing the scope, adjust it's trigger from the generator so that the screen shows the waveform that first arrives at the microphone and not a later reflection. At the lowest frequencies, it is possible for the first reflection to look very much like the impulse (Figure 5).

Once the relative polarity of the test set-up has been determined and the trigger properly adjusted, testing can begin. Whether the test set-up is positive or negative is not important as long as all the adjustments result in the pulse going in the same direction. With the generator putting out a mid-frequency pulse, Figure 6 shows the type of results expected from a five-inch full-range speaker. The erratic waves after the pulse are reflections from the room where the tests were made. As mentioned, the frequency response (Figure 7) will not change regardless of the polarity in a single speaker system.

Figure 8 is the impulse measurement of two five-inch speakers with identical polarity. Figure 9 is the response of the pair. Figure 10 has the polarity of the two speakers opposite one another. Figure 11 is the resulting frequency response. Figure 12 is an overlay of Figure 9 and Figure 11. The efficiency of the two curves was maintained so that a direct comparison could be made. The top trace is of the speakers with identical polarity. The bottom trace has them opposite.

Now that the basic procedure and how to read the impulse is understood, let's take a look at a two-way system. Adjust the frequency control of the generator to a low frequency and observe the polarity of the bass speaker. Re-adjust the frequency on the generator to the crossover frequency and observe the polarity of the woofer and tweeter (Figure 13). The small first peak is the tweeter and the second larger one is the woofer. Both

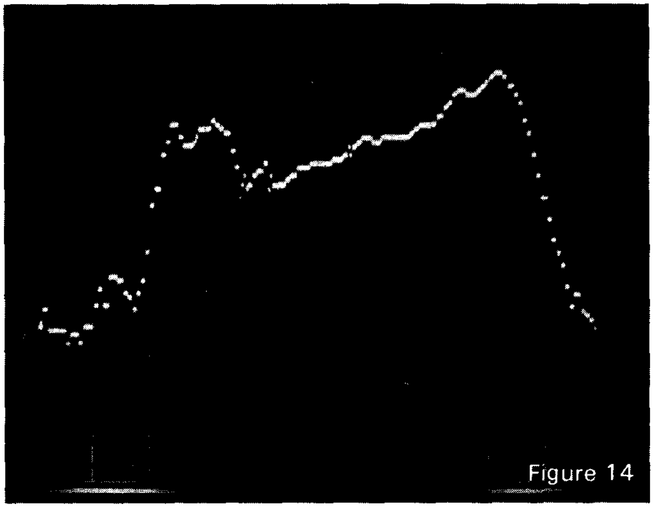
Figure 14

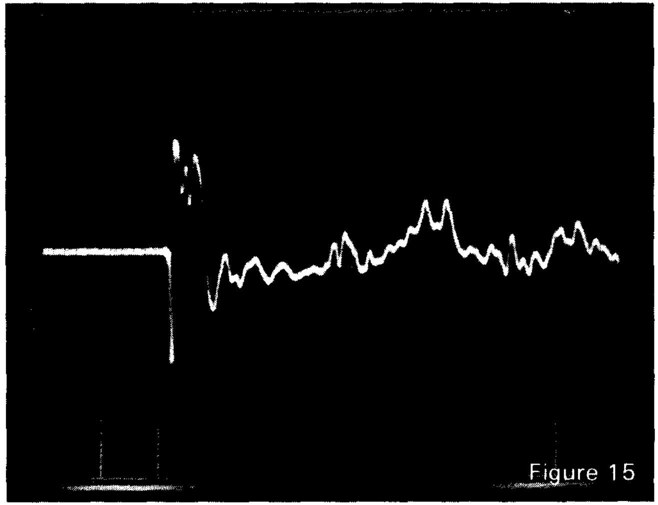
Figure 15

are in the same polarity. Figure 14 shows theresponse. Figure 15 is the same system but with the tweeter polarity opposite that of the woofer. Figure 16 is the resulting response showing a substantial dip at the crossover frequency. Figure 17 again shows a comparison between the system in phase and out of phase response.

The same procedure can be followed with three- and four-way systems. The frequency of the generator is changed to each of the crossover frequencies until the polarity of all the transducers has been determined. If there is more than one driver in any one band range it will be necessary to move the microphone close (one inch) to each driver to eliminate interference from the other drivers in that range.

The effect of band-to-band polarity considerations will result in either a peak or a notch in the frequency response at those crossover points.

Another use of the impulse is to check the polarity of microphones. Once the polarity of the test microphone has been determined, other microphones can be compared to it by connecting each microphone in turn to the oscilloscope. If any of the mikes are out of phase with the majority, then reverse the signal wires on that mike's connector. It should be noted that most European microphones are opposite in polarity to American ones.

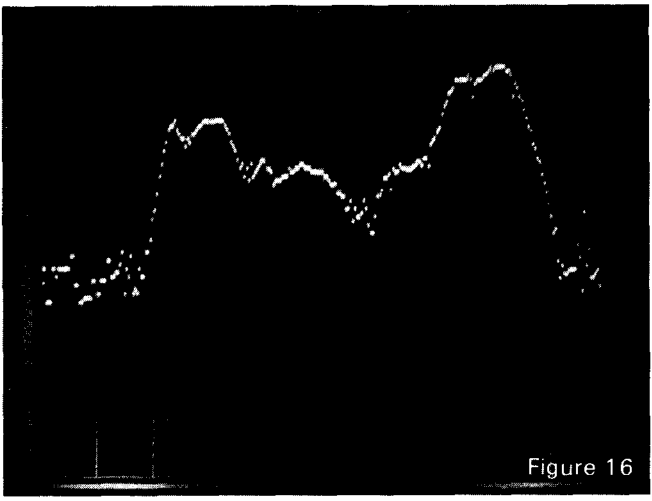

Figure 16

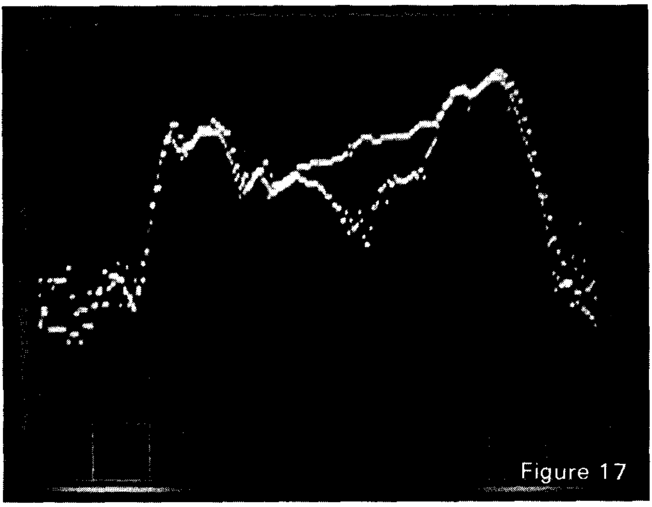

Figure 17

In the second part of this article the impulse will be used to measure cabinet ringing and acoustic phase alignment.

For additional information on this topic Don and Gary have provided the following sources:

"Acoustical Measurements by *Time Delay Spectrometry,"* R. C. Heyser. AES, October, 1967, p. 370.

"Impulse Measurement Techniques for Quality *Determination,"* in Hi-Fi Equipment, with special emphasis on Loudspeakers. JAES vol. 19, p. 101, 1971, A. Schaumberger.

Applications of impulse measurement techniques to the Detection of Linear Distortion, Alfred Schaumberger. JAES September 1971, p. 664.

Linear Distortion, D. Preis. AES, June 1976.

The Application of Digital Techniques to the *Measurement of Loudspeakers,* J. M. Berman and L. R. Fincham. AES, June 1977, p. 370.

Three Dimensional Displays for Demonstrating Transient Characteristics o/Loudspeakers, Tsutomu Suzuki, Takshi Mor II, and Sumitaka Matsumara. AES, July-August 1978, p. 511.0

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