# Driver Parameter Assessment Using Transient Capture Analysis

By Mark Sanfilipo

Try this mathematical approach to derive driver parameters and see how it compares to conventional measurement techniques.

The methods and advantages of time-domain analysis are well known and widely discussed in the literature of loudspeaker system design. This article discusses a quick method of deriving driver parameters from the voltage response as measured at the drivers' input terminals. I'll also provide worked examples and conclude with comparison driver specifications as determined by this method and standard MLS analysis.

## A TIMELY SOLUTION

Fourier analysis shows that an event—be it audio or acoustic—can be described in two ways. Better known in speaker builder circles as the time domain and the frequency domain (*Fig. 1*), the coordinates of these two descriptions (or, more accurately, domains) are dimensionally reciprocal, with one describing the event in units of time and the other describing the event in units of reciprocal time, or as reciprocal time is better known, hertz.

Transforming the event from one domain to the other is accomplished mathematically by application of the Fourier transform (time to frequency domain), or the inverse Fourier transform (frequency to time domain).

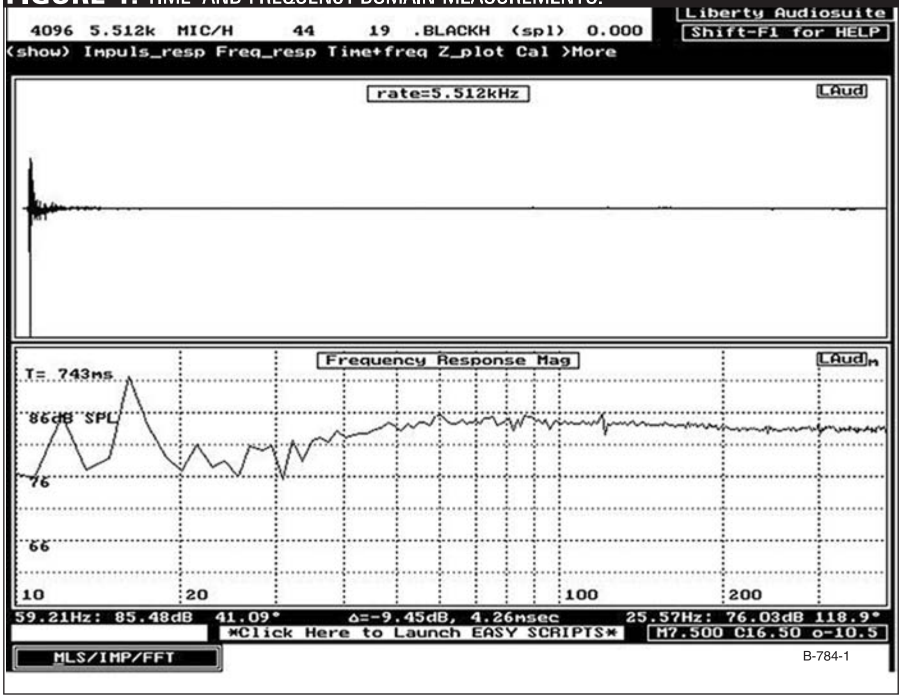
$$x(t) = a_o + \sum_{k=1}^{\infty} (a_k \cos(2\pi k f_o t) + b_k \sin(2\pi k f_o t))$$

## THE FOURIER TRANSFORM

When implemented on a PC with a fast processor, the Fourier transform—or perhaps more to the point, the computationally efficient, Fast Fourier transform—can provide a real wealth of information in a very short period of time. It's impressive just how much information can be derived from that impulse!

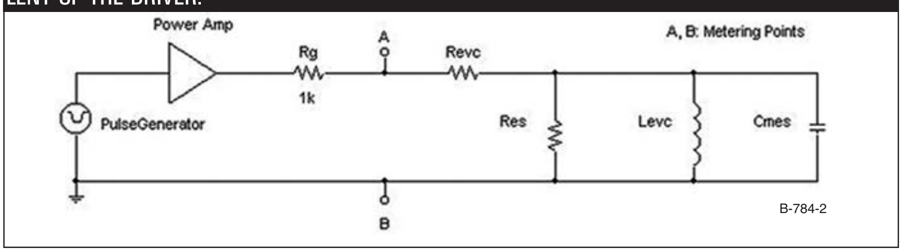
But without resorting to such complex computations, and the hardware/software needed to accomplish them, is it possible to derive useful information with a basic complement of measurement gear, a calculator, and some mathematical effort? This article investigates an algebra-based method for accomplishing just that.

**FIGURE 1:** TIME- AND FREQUENCY-DOMAIN MEASUREMENTS.




**ABOUT THE AUTHOR**
Mark Sanfilipo has been involved in various dimensions of audio since the early 1980s. Beginning as a pro-sound engineer with an interest in exploring ways of building better quality studio and stage monitors, what began as an advanced hobby would later grow into a professional endeavor. Mark splits his time between New York and southern Ontario wine country where he and his wife Penny keep busy raising five kids—all of whom are budding audio enthusiasts.

**FIGURE 2:** THE CIRCUIT VERSION OF THE TEST SETUP, INCLUDING THE ELECTRICAL EQUIVALENT OF THE DRIVER.



## THE IMPULSE TO MEASURE

The setup for measuring the driver parameters is relatively straightforward. At the source end of the chain is, of course, the impulse source. This could be a pulse generator or square-wave generator capable of kicking out appropriate step functions.

The next link in the setup is the power amp set, of course, at a suitably low level to avoid: (a) blowing up the driver being tested and/or (b) pushing the driver into nonlinear operation. It's easy to see how effortlessly a pulse can send a driver into nonlinear operation (or even launch a cone out of its frame!)—so be careful.

The best bet when setting impulse levels is to start with the amp's gain set so low as to present no audible reaction from the driver and then slowly bring it up, watching both the driver and whatever you're using for a display (PC monitor or oscilloscope). I found setting the gain at a level just enough to produce clean, readable, repeatable results, but no higher, worked best. You'll need to spend some time experimenting with both levels and scope settings. If you are planning on measuring more than one of the same driver, save yourself some time and write down the settings.

The resistor Rg has a chosen value many times greater than the driver's free-air resonance impedance peak, and is put in place so that the driver end of the circuit is, in effect, looking at a constant-current source (*Fig. 2*). The common practice is to use a 1kΩ resistor or a resistor with a value 10× higher than the Zpeak. But even these values may be a little low. With an Rg value of 10× the Zpeak, the actual current can drop ≈ 1dB at resonance. Once again, experimentation is key.

You record the voltage response at the input terminals by using a digital storage oscilloscope, or, if one is not available, an ordinary oscilloscope will prove adequate as long as it has a high-persistence CRT.

If you're on a strict budget or would simply rather spend more on the loudspeaker system than the hardware used to build it, electronics surplus outlets are a great place to shop for affordable generators, oscilloscopes, meters, and

### TABLE 1

| VALUES | DEFINITIONS |
|---|---|
| C | Speed of sound in air, ~345 m/s. |
| Rg | The resistor in the circuit to make the driver think it is looking at a constant-current source. (Value: Rg>>Zpeak.) (Ω). |
| Revc | DC resistance of the driver's voice coil. This should be measured before commencing impulse testing for reasons that will become clear shortly (Ω). |
| Res | Electrical resistance due to suspension losses (Ω). |
| Lces | Electrical inductance due to suspension compliance (H). |
| Cmes | Electrical capacitance due to driver cone mass (F). |
| Bl | Driver's force factor (N/A). |
| Mms | Mechanical mass of driver diaphragm assembly including voice coil and air load (Kg). |
| Cms | Mechanical compliance of driver's suspension (m/N). |
| RMS | Mechanical resistance of driver suspension losses (Ω). |
| $Q_{ES}$ | Electrical Q of driver. |
| $Q_{MS}$ | Mechanical Q of driver. |
| Sd | Effective projected diaphragm area ($m^2$). |
| $V_{AS}$ | Equivalent closed air volume of driver compliance ($m^3$). |
| $\alpha$ | Damping constant. |
| $\eta 0$ | Reference efficiency. |
| $\rho$ | Density of air (1.18 kg/$m^3$). |
| $\omega$ | Natural angular frequency (rad/s). |
| $\omega 0$ | Angular resonance frequency (rad/s). |

so on. You'll find quite a few of these places on the Internet. The hardware I used was military surplus gear, purchased from just such an outlet. I've used this sort of gear for years and have found the discounted price paid nets you certainly used, but generally well maintained, equipment. Always ask for the service manuals if available.

On the other hand, if you have a PC equipped with a reasonably good quality sound card (particularly useful if it can function in full duplex mode), a bit of 'net surfing will, in all likelihood, uncover software capable of turning it into a signal generator.

## REAL-WORLD MATHEMATICS

Consider the concepts of *Table 1* and definitions of *Fig. 3*. For my measurements, I used the data presented by the first maxima (Y0, t0), first minima, (Y1, t1), and second maxima (y2, t2). I also measured Revc prior to pulsing the driver. Here's the equation sequence for determining the driver's parameters:

$$T = t_2 - t_0 \quad \text{(sec.)} \qquad (1)$$

$$\omega = \frac{2*\pi}{T} \quad \text{(rad/sec)} \qquad (2)$$

$$f = 1 - \frac{y_0 - y_2}{y_0 - y_1} \qquad (3)$$

$$\alpha = \frac{2*\ln(f)}{T} \qquad (4)$$

$$\omega_0 = \sqrt{\omega^2 + \alpha^2} \quad \text{(rad/sec)} \qquad (5)$$

$$\varphi = a\tan(\alpha/\omega) \qquad (6)$$

$$t_0 = \frac{T}{4} + \frac{a\tan\left(\frac{\alpha}{\omega}\right)}{\omega} + \frac{m*T}{2} \quad \text{(rad/sec)} \qquad (7)$$

$$A_0 = \frac{y_0 - y_1}{1+f} \qquad (8)$$

With Revc known, you then calculate:

$$i*Revc = y_0 - A_0 - y_q \quad \text{(volts)} \qquad (9)$$

$$i = \frac{y_0 - A_0 - y_q}{Revc} \quad \text{(amperes)} \qquad (10)$$

You can now calculate Cmes, Res, and Lces:

$$Cmes = \frac{i*Revc*e^{\alpha*t_0}}{\omega_0 * A_0 * Revc} \quad \text{(farads)} \qquad (11)$$

$$Res = -\frac{1}{2*\alpha*Cmes} \quad \text{(Ohms)} \qquad (12)$$

$$Lces = \frac{1}{\omega_0{}^2 * Cmes} \quad \text{(Henries)} \qquad (13)$$

Pulsing the driver once again, this time with an added mass of known weight, you can then calculate Mms:

Mms = ((Madd)/((fs/fsam)2) − 1 (Kg)
Where: Madd = Mass added to cone (14)
Fs = $\omega/2\pi$ (Hz) (15)
Tmadd = t(y2) − t(y1) (sec.) (16)
= period found after adding mass.
Fsam = ($2\pi$/Tmadd)/ $2\pi$ (Hz) (17)

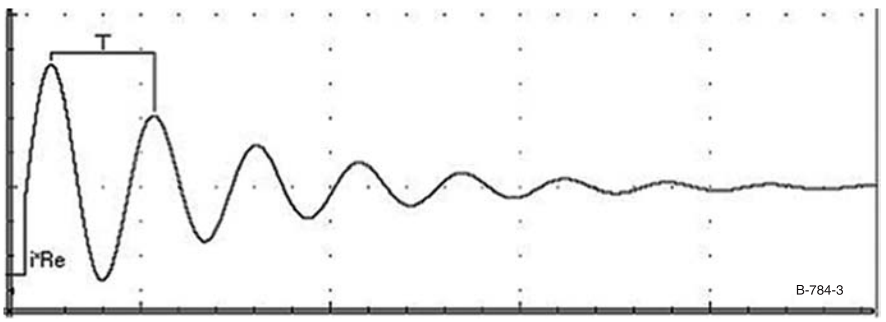
Knowing Mms, you can then calculate Cms:

Cms = (1)/($4\pi^2 \times (fs)^2 \times$ Mms) (m/N) (18)

Finally, you have:
Vas = $\rho \times c^2 \times Cms \times Sd^2$ (liters) (19)
BL = $(Mms/Cmes)^{0.5}$ (N/A) (20)

**FIGURE 3:** VOLTAGE STEP AND SUBSEQUENT OSCILLATIONS.

WHERE:
AN = VOLTAGE MAGNITUDE
I * REVC = VOLTAGE STEP
Y0, T0 = COORDINATE VALUE OF FIRST MAXIMUM (VOLTS, SECS.)
Y1, T1 = COORDINATE VALUE OF FIRST MINIMUM (VOLTS, SECS.)
Y2, T2 = COORDINATE VALUE OF THE 2ND MAXIMUM (VOLTS, SECS.)
YQ = PRE-PULSE VOLTAGE
T = PERIOD OF THE OSCILLATION (SECS.)



$$Qmes = Res \times Cmes \times \omega o \quad (21)$$

$$Qes = Qms \times Revc/Res \quad (22)$$

$$Qts = 1/((1/Qms) + (1/Qes)) \quad (23)$$

$$\eta 0 = (4\pi^2 \times fs^3 \times Vas)/(c^3 \times Qes) \quad (24)$$

$$SplRef = 112.2 + 10 \times \text{Log}(\eta 0) \text{ (dB Spl/1W/1m)} \quad (25)$$

## A WORKED EXAMPLE

I performed a series of trials on each of four KEF B-139 woofers, two of which were from earlier SP1044x series and two of which were a more recent version, the SP1333x. The numbers shown are taken from a measurement run done on one of the older KEFs. I measured all drivers using both LMS and Liberty Instrument's Laud v. 3.12.

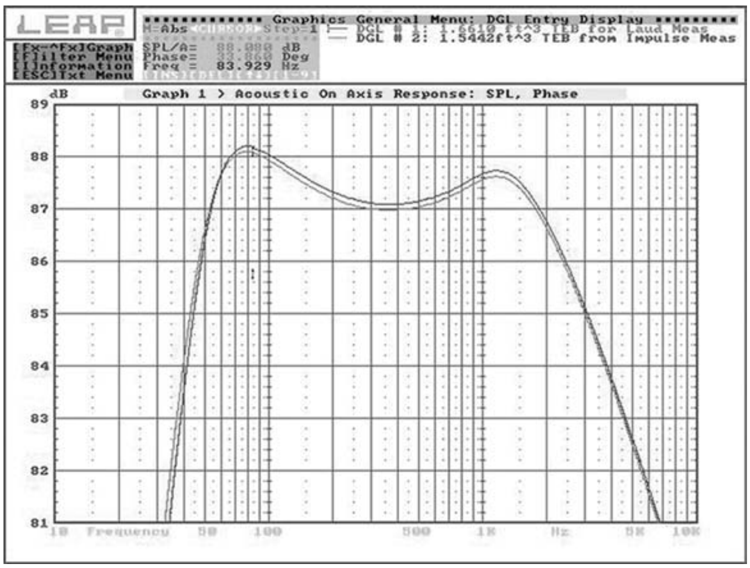
I'll present here for quick comparison the results as taken from a Laud measurement and as derived from the impulse response, plugging the various (y,t) values into the series of equations as previously mentioned.

| **Laud** | **The Math Method** |
|---|---|
| $f_s$ = 36.46Hz | $f_s$ = 36.93Hz |
| $Q_{ES}$ = 0.699 | $Q_{ES}$ = 0.696 |
| $Q_{MS}$ = 6.987 | $Q_{MS}$ = 5.85 |
| $Q_{TS}$ = 0.635 | $Q_{TS}$ = 0.622 |
| $V_{AS}$ = 53.6 ltr | $V_{AS}$ = 53.2 ltr |
| Bl = 12.152 T-m | Bl = 12.22 T-m |
| Cms = 0.3131 mm/N | Cms = 0.3081 mm/N |
| Mms = 60.864 gm | Mms = 60.287 gm |
| η0 = 0.357% | η0 = 0.377% |
| SPLref = 87.5dB | SPLref = 87.97dB |
| fsam = 22.72Hz | fsam = 22.86Hz |

For a final, certainly more definitive comparison, I modeled both sets of parameters in LEAP with the intention of seeing how system responses would compare (*Fig. 4*).

The frequency response plots match to within 1dB at all frequencies of interest. Note the 1dB/division y-axis scale. *aX*

**FIGURE 4:** MATH VS. MEASUREMENT COMPARISON




B-784-4