MAGNETIC CURRENT DRIVERS FOR BULK-INJECTION TESTING

Practical considerations in the use of magnetic current drivers for bulk-injection applications are reviewed.

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INTRODUCTION

The effects of electromagnetic pulse (EMP) environments on systems have been typically evaluated by illuminating an entire system in an EMP simulator large enough to accommodate the system. One of the phenomena of interest in these tests is the current that flows between the various subsystem elements on the interconnecting cables when the system is exposed to an electromagnetic environment. These currents are termed bulk currents since they are a measure of the total current flowing in those cables as bulk entities rather than as a measure of each individual conductor current. The bulk current measurement is the sum of all the individual conductor currents, but does not reflect how the bulk current is divided among the individual conductors. The individual currents are of great importance in the design of individual subsystem elements commonly termed Line Replaceable Units (LRU). However, in bulk-injection verification testing for LRU tolerance to damage and upset in an application environment, the stress is defined in terms of the bulk cable current, often without attention to individual conductor currents. Within the general practice of direct-drive testing, there is increasing interest in monitoring individual pin stress with bulk excitation, but the procedure and equipment are still in a state of definition and development.

Simulators capable of illuminating total systems are expensive to construct and operate. As a result, there are relatively few of these simulators available to perform general validation testing. An alternative to full-illumination testing is bulk-injection testing. Since the accurate assessment of LRU performance depends on verifying proper operation with specific bulk currents impressed on its interconnecting cables, the test may be performed, at least in theory, by any means that establishes the required bulk currents in the LRU cables with the LRU in a mission-representative electromagnetic configuration. These currents may be effectively induced by magnetic or capacitive coupling. Opinions on various methods of bulk-injection testing and the validity of the test results abound. Those issues are well beyond the scope of this work. This article will briefly review the performance of magnetic coupling devices for bulk injection of specified currents.

INJECTION OPTIONS

There are several suitable methods to establish bulk currents. The simplest method is a direct connection of the pulse-power source to the cable of interest. However, that is practical only when the cable has a conductive sheath such as a braided shield or conduit. Also, it may be of interest to drive only the cable conductors in the case of a shielded cable. When the cable has no such sheath, or when bulk injection into the cable conductors only is required, a section of sheath can be placed around a length of the cable. This is a capacitive coupler. One disadvantage of this method of coupling is that the available capacitance is relatively low and that it will require comparatively high source potentials at the lower test frequencies. This generally requires that the coupler be relatively long in order to exhibit enough capacitance to allow useful low-frequency coupling. Another subtle problem with capacitive coupling is that the injected current flow is from the coupler out to each end of the driven cable. Actual bulk currents are more commonly expected to flow along the cable from one end to the other. The unrealistic current distribution established by a capacitive coupler is of little consequence in a test application where the LRU is driven from some type of host system simulator. In this instance the simulator itself is not usually a part of the test and must be hardened against the test signal so that it does not provide an anomalous response. However, in an application where two LRUs are interconnected and a bulk current is injected on their interconnecting cable, capacitive coupling generally provides an unrealistic current distribution.

An example might be a lightning response simulation on a piece of avionics normally installed in the fuselage of an aircraft and connected

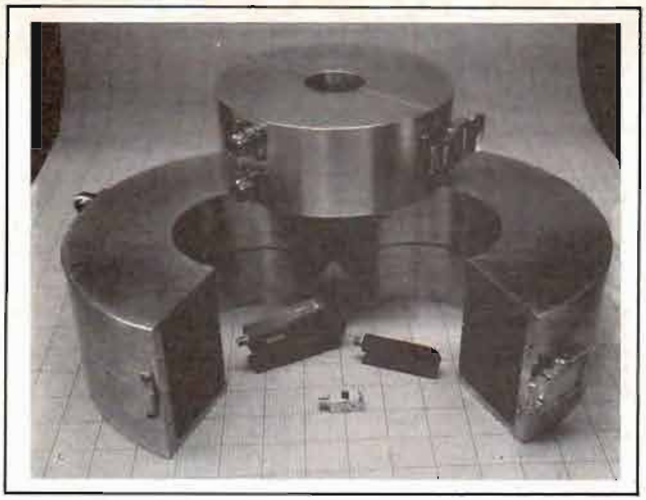


Figure 1. Typical Magnetic Current Drivers for Bulk-injection Testing.

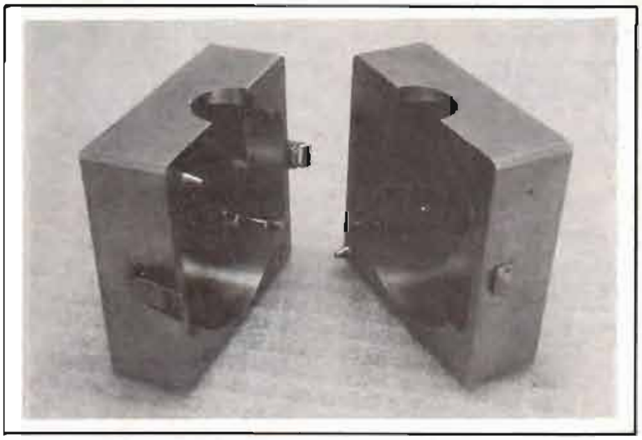


Figure 2. Typical Test Fixture for Current Drivers and Current Probes.

to an active wing-mounted sensor. In a test with the avionics interconnected to the sensor in a simulated air frame, the capacitive coupler would drive currents into both the sensor and the avionics with the same polarity. The more likely threat current would be from the sensor to the avionics (and the reverse).

Another common method used for injecting bulk currents is via magnetic coupling and magnetic current drivers. The use of magnetic coupling provides a more realistic current distribution in most bulk-injection applications. Also, magnetic couplers may be fabricated in a wide variety of sizes and configurations to suit the various test demands of size, peak current, frequency response, etc. In general, a magnetic current driver will be considerably smaller than a comparative capacitive coupler of the same low-frequency capability. However, the high-frequency performance of the magnetic current driver will be somewhat poorer than that of the capacitive coupler.

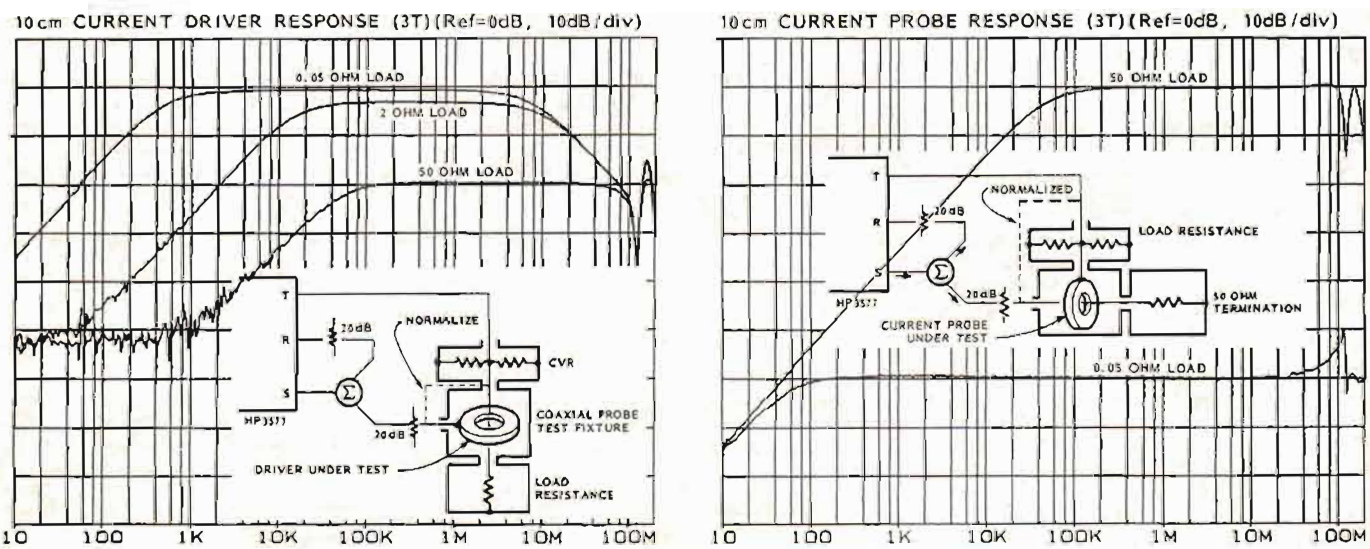
MAGNETIC CURRENT DRIVER CHARACTERISTICS

The magnetic current driver can provide both a realistic bulk-current distribution and the versatility in configuration typically demanded by various test applications. Several typical current drivers with bores ranging from 1 mm to 10 cm are shown in Figure 1. All are clip-on types which can be placed around the conductor without breaking the conductor. The basic driver is easily fabricated as a thread-on unit, but that is much less convenient than a clip-on design. The practical sizes of drivers are not limited to these examples. However, there is a tradeoff in performance with physical size. As the driver is made smaller, the core area is reduced which causes the core to saturate at lower drive levels. The physical length of the winding becomes shorter and raises the ultimate cutoff frequency. As the driver is made larger, the core area is increased and the drive level that the core can handle rises, but the winding length increases and the ultimate cutoff frequency is reduced.

A current driver is merely a transformer where the cable under test forms one or more turns and the pulse-power source is applied to a drive winding of one or more turns. To accurately characterize a driver, a low inductance test fixture is required. A typical test fixture is shown in Figure 2. It should be understood that the use of such a test fixture is intended only to characterize the driver as accurately as possible. The fixture is not in any way intended to represent an actual application environment. The performance of the driver in an actual application is a function of the physical test configuration. Since the manufacturers of current drivers have no information on, or control over, the actual test configuration, they cannot provide accurate data on driver performance in specific application environments. The most useful information that they can provide is accurate electrical performance of the driver in an optimal environment. That information may then be used with actual application data to predict performance and to select suitable drivers.

The frequency response of a typical current driver is shown in Figure 3a with three different load resistances. Since the current driver functions as a transformer, it may be used very effectively as a current sensor, or current probe. Generally, a driver differs from a current probe in that the driver incorporates a much larger core for a given current capability. The saturation of a current probe can be controlled by the loading applied to the probe output. In the use of a driver, loading cannot be used, so the core area must be increased to allow comparable currents to be handled in the driven winding without saturation. The current probe response of the same driver characterized in Figure 3a is shown in Figure 3b. This particular unit is a three-turn device with a 10-cm (4-inch) aperture. It is chosen since a driver of this large size nicely demonstrates both the low- and high-frequency characteristics needed to build a simplified model[1]. The driver test circuit block diagram included in Figure 3a shows that the test system was normalized by tying the 50-ohm source directly to the 0.05-ohm current-viewing resistor (CVR). This method of normalization removes any anomalous response of the CVR as well as the other elements not associated with the actual driver response. The 20-dB pad in the source path isolates the power splitter from the mismatch of the CVR during normalization. This results in an almost ideal source with a source impedance of 50 ohms so that performance with severe mismatches such as that of the CVR and the driver can be very accurately characterized. The plotted response is then a ratio of the current delivered to the test load to that which would be delivered to the load from an ideal 50-ohm source. Again, these data are not intended to have any direct meaning to an application environment but are intended to accurately characterize the driver performance in a well-defined environment which will allow the prediction of its performance in other environments.

In Figure 3a, the 0.05 ohm loaded response shows a low-frequency break at about 800 Hz and a high-frequency break at about 8 MHz. The low-frequency break is caused by the time constant of the magnetizing inductance and the effective impedance across it. The high-frequency break is caused by leakage reactance due to the imperfect coupling of the two windings. This leakage reactance may be modeled as a series inductance in either the primary or secondary circuit, or both. The output of this driver in the mid-band is 9.5 dB above the normalized reference which is precisely the level that is expected from a three-turn unit in the configuration shown in the block diagram of Figure 3a. This implies that at drive levels well below saturation, there are essentially no losses. Finally, just beyond 100 MHz, a sharp anomaly is seen in each response characteristic. The anomaly is due to the resonance effect of the physical length of the driver winding, which causes the ultimate cutoff of this particular transformer geometry. Based on the response of Figure 3a, the simplified model shown in Figure 4 is suggested (other models are, of course, equally acceptable). This is a lossless transformer with zero winding resistance and negligible core loss which implies operation well below core saturation. The magnetizing and leakage inductances determine the lower and upper cutoff frequencies as a function of winding loading, and the ideal transformer transformation ratio in the passband. The ultimate cutoff caused by the winding length is not modeled since it would



a. Driver Response

b. Sensor Response

Figure 3. Performance of a Typical 10-cm, 3-Turn Driver as Both Driver and Sensor.

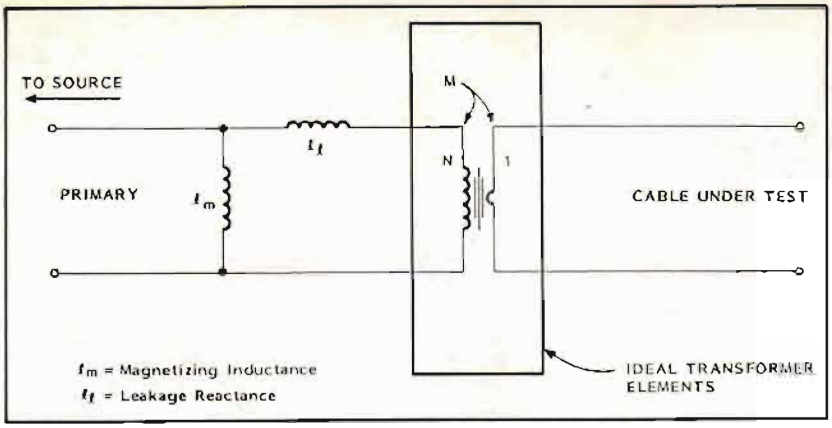


Figure 4. Simplified Transformer Model.

complicate the simple model. However, when using magnetic drivers, particularly driver geometries of 4-cm bores and larger, one should be aware of this limitation in the performance.

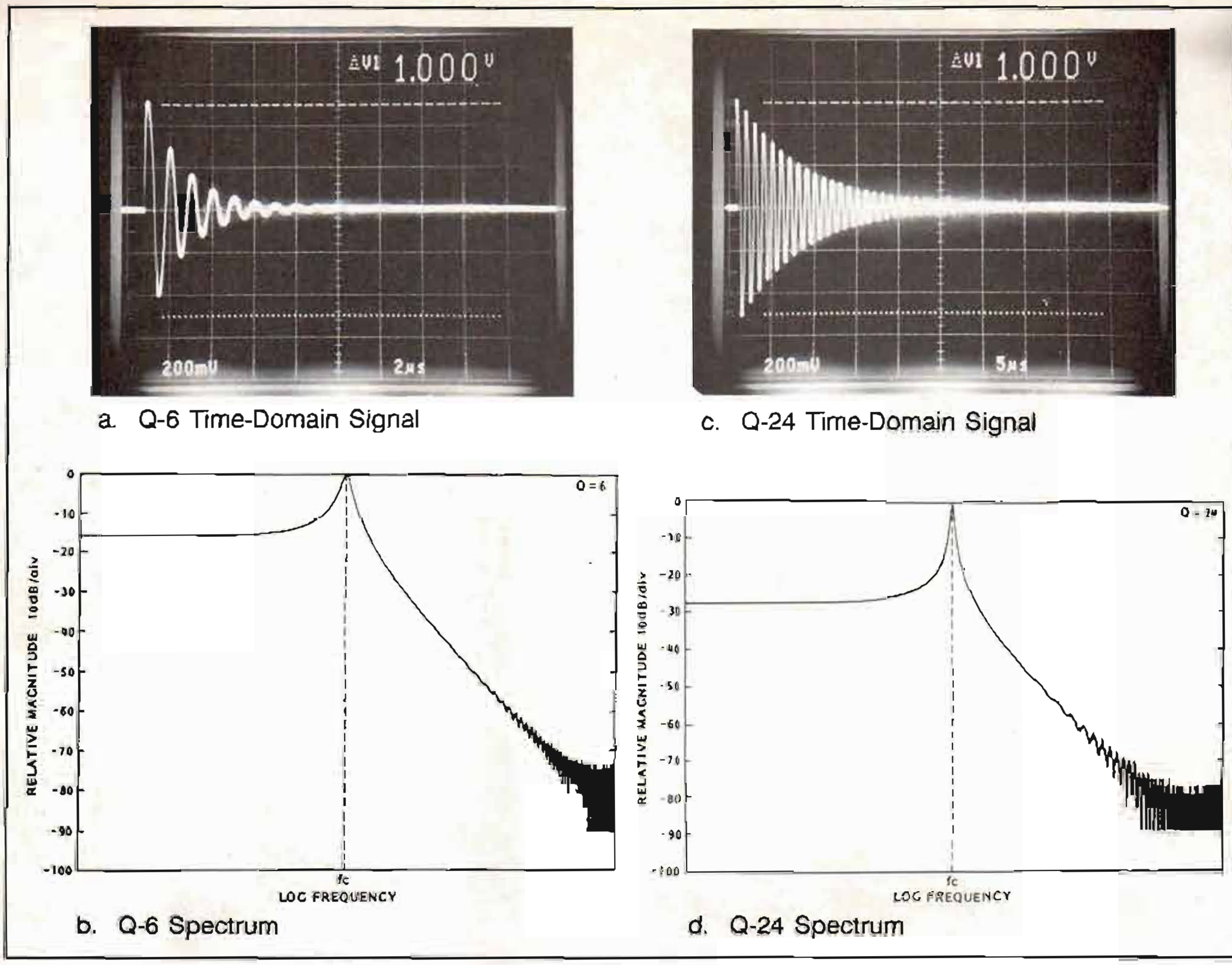
MAGNETIC CURRENT DRIVER FREQUENCY RESPONSE

The actual response required of a current driver is a function of the application. If it is to be used for cw drive, the frequency response is of concern only in its effect on the required source drive capability. If the driver is to be used to inject transient signals, the required frequency response is a function of the actual waveform that must be injected. Ideally, the driver should pass all of the significant spectral components of the test waveform. A typical test waveform for transient bulk-injection testing is the damped sinusoid. Two typical damped sinusoids common in testing are those with Q values of 6 and 24. These two waveforms as output from a commercial damped sine generator are shown in Figure 5 along with the respective analytic spectra of ideal waveforms. The spectrum of the damped sinusoid shows a flat component from dc to near the characteristic frequency. It peaks at the characteristic frequency and then drops with a characteristic that is asymptotic to -40 dB/decade. To faithfully reproduce this waveform, the drive system must have a lower cutoff frequency about a decade below the lowest characteristic frequency of interest and about an octave above the highest. The typical range of test frequencies is 10 kHz to 100 MHz so an ideal driver should have a frequency response of about 1 kHz to 200 MHz. Figure 6 shows the frequency response of a 4-cm aperture driver with both 3 turns and 1 turn. Based on the 1 kHz to 200 MHz requirement, this response is much less than ideal. Since this represents the general response available from a magnetic driver, it would be of value to look at the actual performance of several typical drivers and the effect of their response characteristics on the injected signal. The value of optimization of the driver for specific applications can also be demonstrated.

The performance of several drivers and configurations are demonstrated below. All of this data was collected using a linear RF power amplifier pulsed-power source. The bandwidth of the total pulsed-power system was approximately 1 kHz to 200 MHz and the system was configured in a parallel push-pull configuration to provide good waveform symmetry[2]. In that configuration, its output impedance was nominally 50-ohms and its maximum output power about 12 kW peak. All of the coupled drive data shown were measured across the 0.05-ohm CVR in a test configuration similar to that shown in the block diagram of Figure 3a. That provided consistency in the collected data which allows a simple comparison of the various coupled signals. With the 0.05-ohm CVR, the conversion factor from displayed potential to delivered current is 20 amperes per volt. The digital voltmeter cursor function of the measurement oscilloscope was used to provide an accurate display of the specific quantity of interest in each case. In several cases some attenuation was necessary to allow display of the desired data on the oscilloscope. For those data, a scale factor is necessary to determine the actual signal potential from that indicated on the photographs. The scale factor for each of those photographs is given in volts per volt where applicable. Where no scale factor is shown, a 1 V/V factor is understood and the displayed value is the actual value of interest.

Figure 7 shows the performance of the 4-cm driver characterized in Figure 6 with a damped sinusoidal waveform with Q-24 at characteristic frequencies of 10 kHz, 1 MHz and 100 MHz loaded into the 0.05-ohm CVR. Additionally, at 100 MHz the performance into a 50-ohm load is also shown. The drive level of 200 A peak-to-peak for the two lower frequencies was selected to be well below the maximum limits of the linear power amplifier source used but sufficiently high to show some of the amplitude-related distortion typically expected. The levels at 100 MHz are about the maximum available for the particular source and driver at that frequency.

From these data, it is seen that the low-frequency performance is best at the lower load impedance and that the high-frequency performance is best for the higher impedance loads. That is precisely what can be expected from the frequency-response data. At 10 kHz, the waveform envelope is distorted (first positive and negative cycles) because the low-frequency cutoff of the driver (and the am-



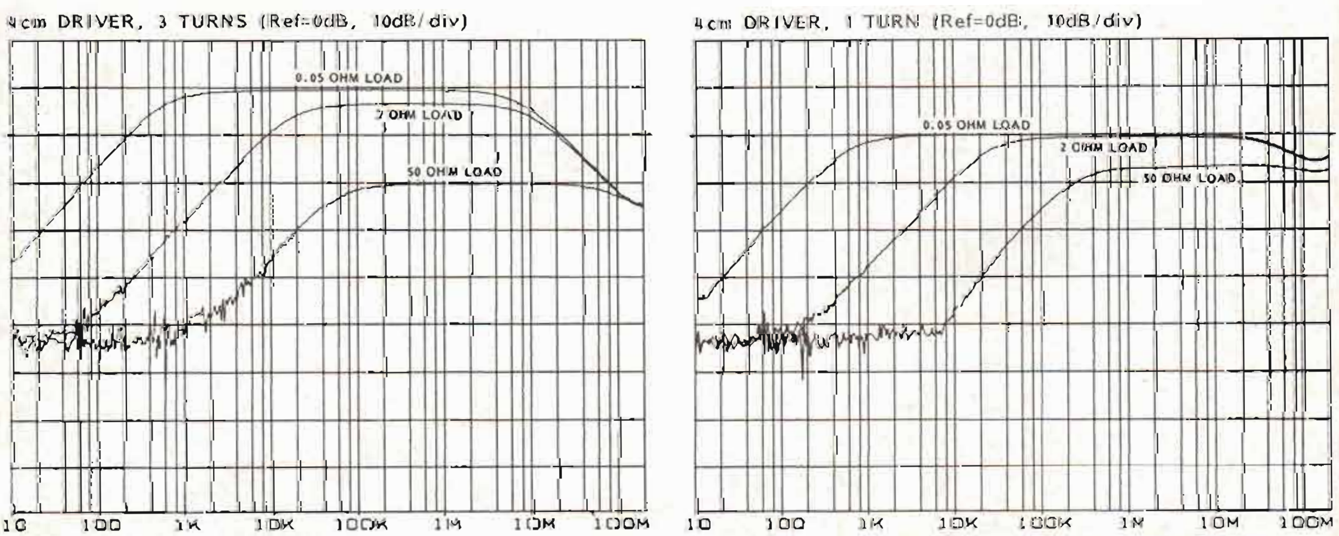
a. Q-6 Time-Domain Signal

c. Q-24 Time-Domain Signal

b. Q-6 Spectrum

d. Q-24 Spectrum

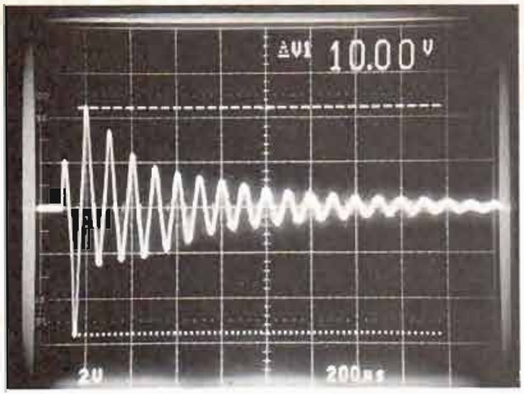
Figure 5. Two Common Damped Sinusoidal Test Signals and Their Spectra.



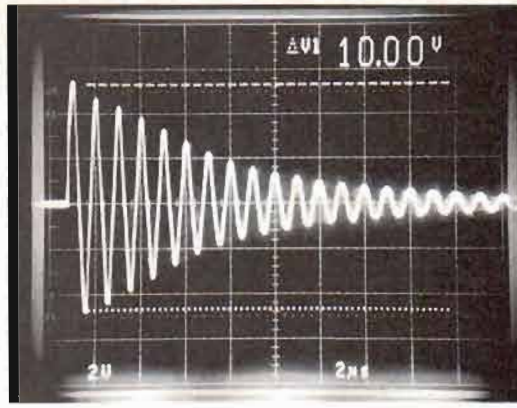
a. 3-Turn Response

b. 1-Turn Response

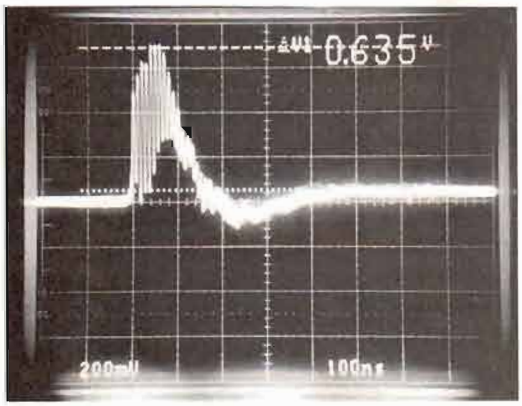
Figure 6. 4-cm Driver Performance with 3-Turn and 1-Turn Windings.



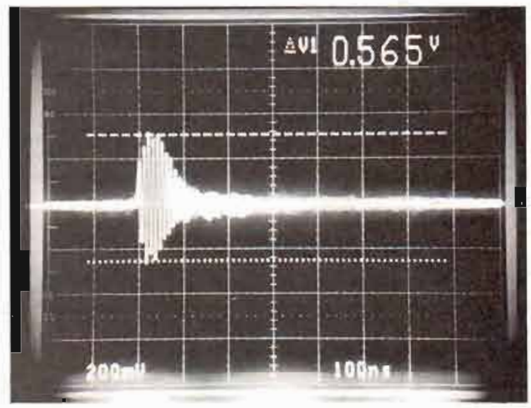
a. 10 kHz, 0.05-Ohm Load



b. 1 MHz, 0.05-Ohm Load



c. 100 MHz, 0.05-Ohm Load



d. 100 MHz, 50-Ohm Load

Figure 7. Transient Performance of a 4-cm, 3-Turn Driver at Various Characteristic Frequencies and Load Resistances (0.05-Ohm CVR Potential).

plifier system to some extent) is too high. Also, some slight cross-over distortion is seen at the zero crossings. This is an artifact caused by the push-pull amplifier configuration. At higher drive levels, this cross-over distortion is typical of push-pull RF amplifiers where the drive transfers alternately from the "pushing" amplifier module to the "pulling" module.

At 1 MHz, some slight distortion at the peak of the first positive cycle is seen which is caused by amplifier drive limitations, but in general, the wave shape is quite good. At 100 MHz into a 0.05-ohm load, the coupled current presents a very bizarre appearance. This again may be explained from the driver frequency response and the spectral components of the damped sinusoid. From the damped sine spectra in Figure 5, it is seen that there is considerable spectral energy in the range below the characteristic frequency. Examining the 3-turn driver response for a 0.05-ohm load in Figure 6a, it is seen that much of the low-frequency spectral contribution is passed at a level more than 20 dB greater than that of the characteristic frequency at 100 MHz. This results in the damped sinusoid being delivered at a reduced level and modulated by a low-frequency, low Q, damped sinusoidal characteristic. This is certainly a less than desirable test waveform. It is difficult to quantify the effect of this unusual waveform on the system under test, and the available drive level is reduced to about 13 A p-p from the 200 A p-p at midband. The frequency response for this driver with a 50-ohm load suggests a better performance at the higher frequencies than that for the 0.05-ohm load. Figure 7d shows the signal injected into a 50-ohm load by this same driver. The available drive is still quite low, about 11 A p-p, but the waveform symmetry is much better since the low-frequency artifact is eliminated. This is due to the higher upper cutoff frequency of this driver when operating into this load as shown in Figure 6a. This waveform is still much less than an ideal damped sinusoid, but it is typical of that seen at the higher test frequencies (the input waveform at all test frequencies is essentially identical to that shown in Figure 6a).

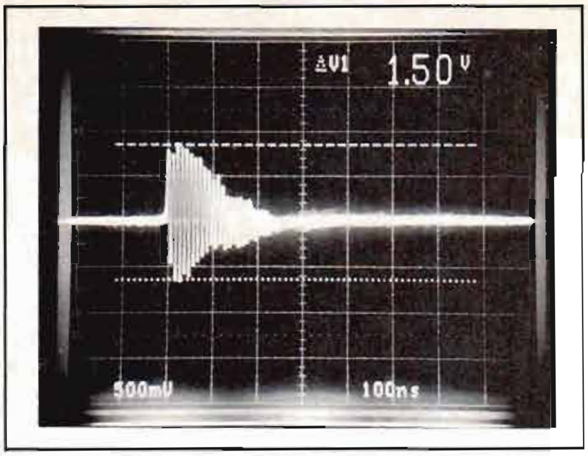
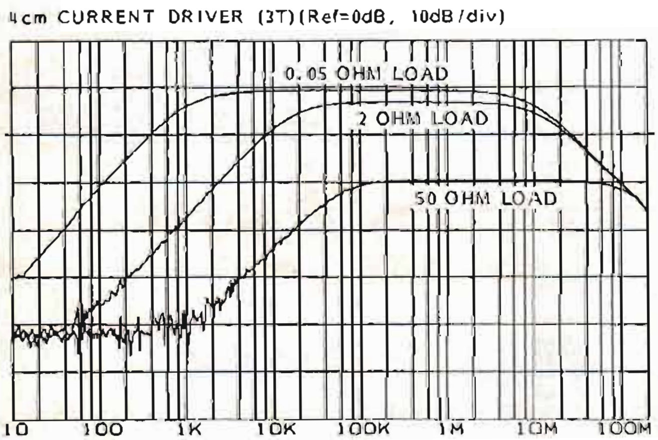
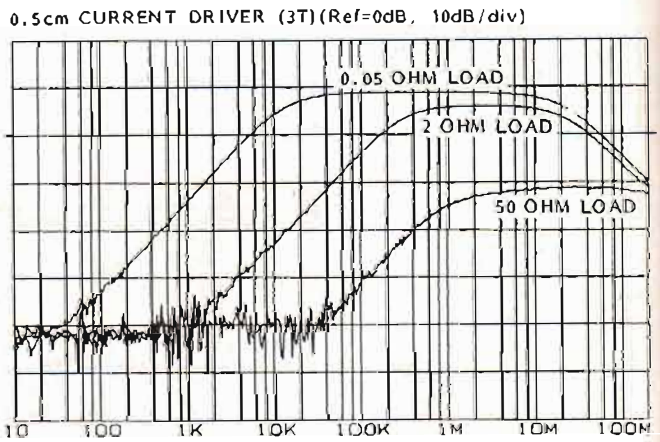


Figure 8. Damped-sine Performance of a 4-cm, 1-Turn Driver into a 0.05 Ohm Load (0.05-Ohm CVR Potential).

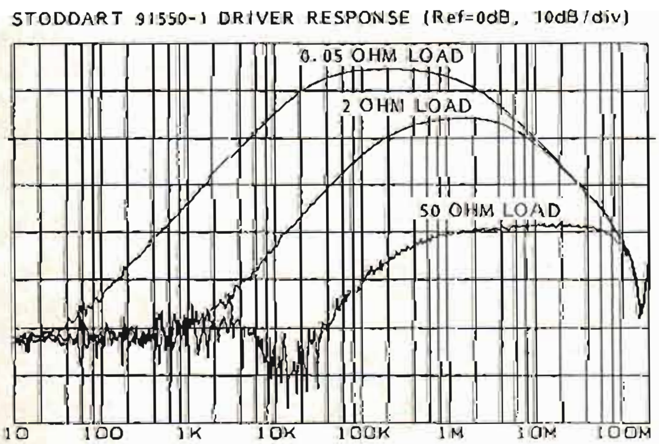
Reducing the driven primary winding from three turns to one results in the frequency response of Figure 6b. As expected, the midband performance is that of a 1:1 transformer. The low-frequency cutoff is approximately the same as that of the three-turn configuration. The magnetizing inductance is ideally reduced by a factor of nine for a three-to-one turns reduction. That alone would suggest that the lower cutoff frequency should increase by about a decade. However, in the model of Figure 4, the total primary winding load is the parallel combination of the 50-ohm source impedance and the transformed load impedance. Since the transformed load impedance is very much smaller than the source impedance, it is the predominant compo-



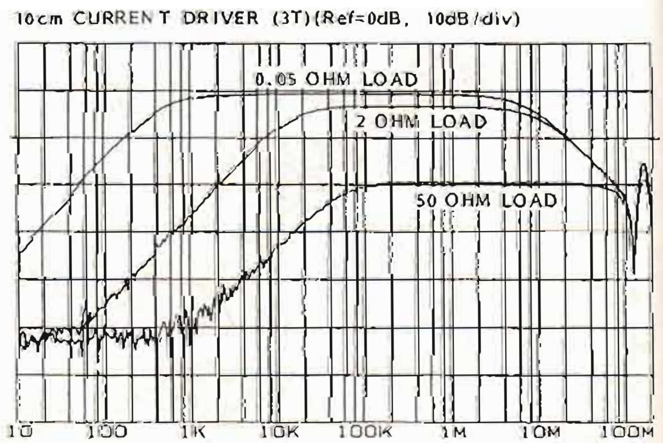
a. 0.5-cm, 3-Turn



b. 4-cm, 3-Turn



c. 10-cm, 3-Turn



d. Stoddart 91550-1 as a Driver

Figure 9. Response of Three Drivers and a Stoddart Probe Used as a Driver.

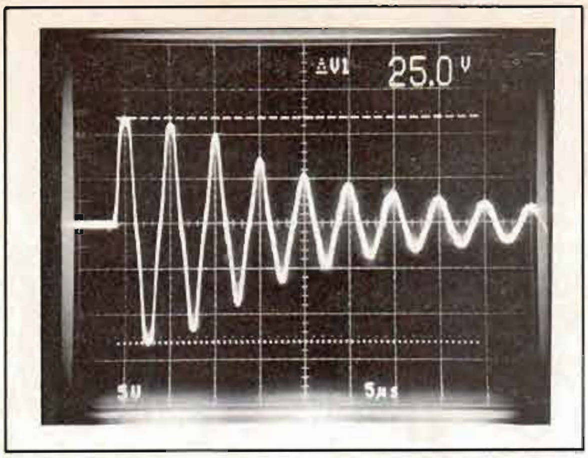


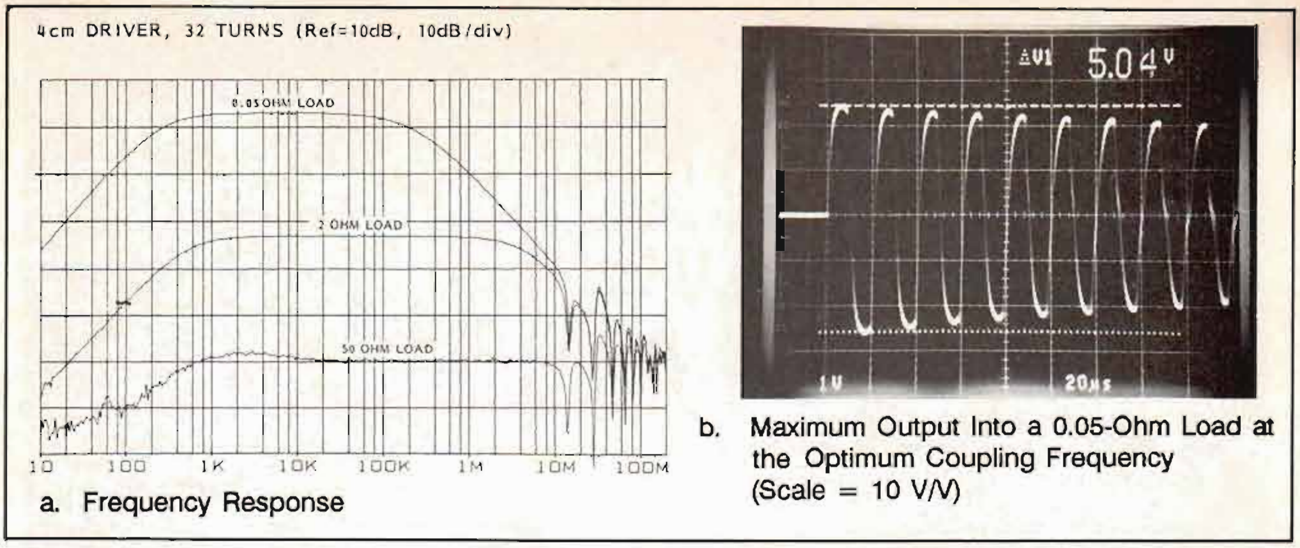
Figure 10. Maximum Output From a 91550-1 into a 0.05-Ohm Load at the Optimum Coupling Frequency (0.05-Ohm CVR Potential)

nent of the primary load which determines the lower cutoff frequency. When the turns ratio is reduced from 3:1 to 1:1, both the winding inductance and the total load resistance across it decreases by a factor of nine. The primary circuit time constant of the primary magnetizing inductance divided by its load resistance (which determines the low-frequency cutoff) then remains constant with the result that the lower cutoff frequency remains constant for the 3-turn to 1-turn change with the 0.05-ohm load resistance.

The upper cutoff frequency of the 1-turn configuration is more significant than the lower cutoff frequency. For the 0.05-ohm load, the upper cutoff frequency increased from about 8 MHz for the 3-turn unit to about 80 MHz for the 1-turn device. This is due to the lower leakage reactance of the 1-turn device. Comparing the 0.05-ohm responses in Figure 6a and 6b, it is seen that the 1-turn midband response is about 10 dB below that of the 3-turn unit. For the 3-turn configuration, the 100 MHz response is down by about 21 dB from its midband response while the 100 MHz response for the 1-turn configuration is about 4 dB down from the midband response. That implies that the available drive to the 0.05-ohm in the midband is 10 dB higher for the 3-turn device, but at 100 MHz, the available drive from the 1-turn unit is actually more than 7 dB higher than for the 3-turn unit. The performance of these two configurations in reproducing damped sinusoids up to about 10 MHz can be expected to be about the same with the coupled drive of the 1-turn unit about one third that of the 3-turn unit. However, the 1-turn unit can be expected to reproduce damped sinusoids near 100 MHz with much better fidelity and with the higher coupled level than the 3-turn unit because of its higher high-frequency cutoff. Figure 8 shows the 100 MHz damped-sine signal coupled into a 0.05-ohm load with the 1-turn device. The available current is about 30 A p-p. This is an improvement of about 7.5 dB over that shown in Figure 7c for the same driver with 3 turns. Further, the wave shape of the injected signal is much improved over that of the 3-turn unit driving the same load at the same frequency. This improved high-frequency performance is, however, obtained at the expense of reduced drive available in the midband. To optimally drive the variety of loads typical of bulk-injection testing, the driver performance must be well understood to allow the selection of the best driver configuration for each specific load.

For a comparison of various drivers, Figure 9 shows the response of three, 3-turn drivers with 0.5-cm, 4-cm and 10-cm apertures respectively and the driver performance of a Stoddart (now Ailtech) 91550-1. This unit is an industry standard current probe that may be effectively used as a driver. The 91550-1 uses the 50-ohm impedance of the driven circuit as its load and therefore uses no internal load. It may then be used directly as a driver. The midband level available from this unit is quite good. Figure 10 shows the output signal at the optimum driver frequency of 200 kHz and at roughly the same drive level used in Figure 7b. The current available from the 91550-1 at 200 kHz is about 500 A p-p while that of the 3-turn unit of Figure 7 was only about 200 A p-p for the same input. However, the performance of this unit as a driver over the entire test spectrum will be poor due to its relatively narrow bandpass characteristic. This is not a criticism of the performance of the 91550-1, but a demonstration of its performance in an application for which it was never intended. Nevertheless, it can be used quite effectively if its performance is understood.

This shows that the 91550-1 can inject much higher levels at certain frequencies than the 3-turn units examined. However, almost any driver can be optimized for maximum output. In general, the maximum current that can be coupled to a load is determined ultimately by the available drive from the source. As an additional comparison, the 4-cm driver used in the examples above was configured with a 32-turn winding. This winding results in an optimum power transfer between the 50-ohm resistive source and the 0.05-ohm resistive load, and therefore induces the maximum available current into the 0.05-ohm load from the 50-ohm source. Figures 11a and 11b show the frequency response of this configuration and the maximum available output at the optimum driver operating frequency (about 50 kHz). This shows that a drive cur-



a. Frequency Response

b. Maximum Output Into a 0.05-Ohm Load at the Optimum Coupling Frequency (Scale = 10 V/V)

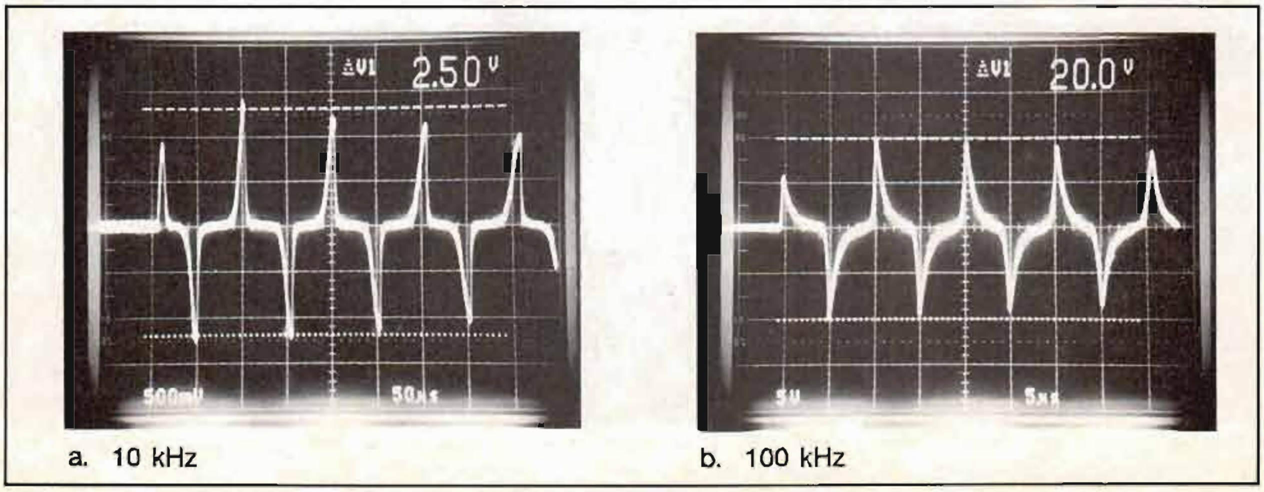
Figure 11. Performance of a 4-cm, 32-Turn Driver into a 0.05-Ohm Load with a 50-Ohm Source.

rent of about 1000 A p-p is provided with this 32-turn configuration. That drive current is limited by the drive available from the linear amplifier (about 12 kW peak). Further, it will provide better performance than the 91550-1 used as a driver because of its better frequency response (a bandpass greater than nine octaves compared to slightly less than six for the 91550-1). This configuration provides good performance from the lowest frequencies of interest to perhaps a few hundred kilohertz. At higher frequencies, a configuration with fewer turns will actually provide better performance.

DRIVER SATURATION CHARACTERISTICS

Since typical current drivers contain magnetic core material of some type, that core will become saturated with sufficient drive. Operating a driver in saturation is not generally a damaging mode in low duty-cycle pulsed applications, but the coupled waveform will suffer severe distortion. However, when the driver saturates, it effectively becomes a short circuit to the source which results in high currents in the primary winding. A very low duty cycle must be maintained to prevent thermal damage to the physical winding of the driver.

Figure 12 shows the response of a 0.5 cm driver driven into hard saturation at 10 kHz and 100 kHz. A 0.5 cm driver was selected since it is very easily saturated with the available amplifier system, and it exhibits a classic saturation response. The signal delivered at 10 kHz is about 50 A p-p in Figure 12a and about 400 A p-p at 100 kHz in Figure 12b. These are relatively high currents from that small driver, but the waveform suffers the severe distortion seen in Figure 12. At a given peak, the core saturates and the time rate-of-change of flux essentially drops to zero causing the in-



a. 10 kHz

b. 100 kHz

Figure 12. Saturation Performance of a 0.5-cm, 3-Turn Driver into a 0.05-Ohm Load (0.05-Ohm CVR Potential).

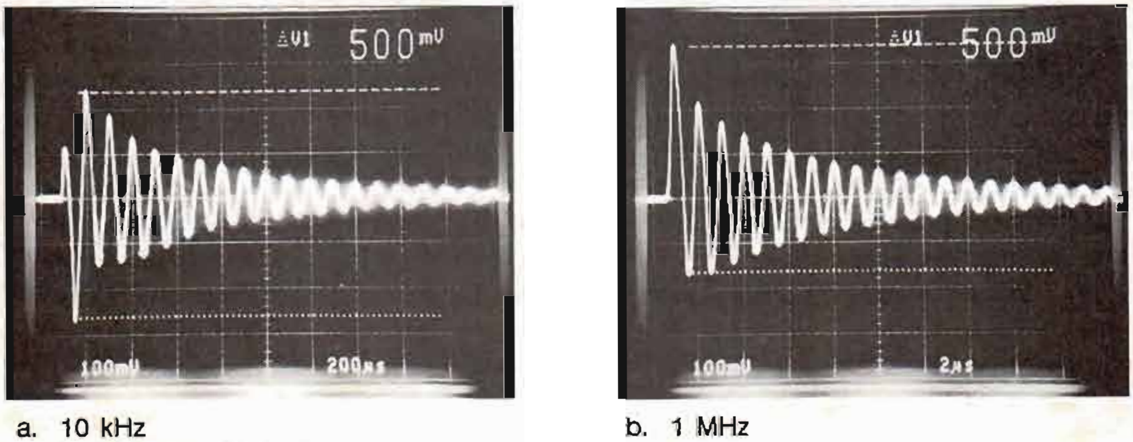
jected signal to also fall to zero. This is clearly seen in Figure 12a at 10 kHz. As the source drive cycle reverses, the flux is driven from saturation in one polarity through zero to saturation in the other polarity (the first cycle is about one-half as large as successive peaks since the first flux transition is from zero flux to saturation in one direction). During the flux swing from one saturation point to the other, a corresponding signal is induced into the load.

The output level can generally be increased with increased input drive (within limits), but at the expense of additional distortion. The saturation characteristics of a driver depends greatly on core material characteristics and the physical design of the driver. Since waveform fidelity is usually an important parameter in most testing applications, operation in saturation is a rather undesirable mode. However, for low-impedance loads, relatively high peak currents may be coupled with small geometry drivers. The unit used for the data of Figure 12 was only about 2 inches (5 cm) long, 0.75 inches (1.9 cm) wide and 0.35 inches (0.89 cm) thick (the center-right unit in Figure 1), yet it provided a 200 A peak drive to the 0.05-ohm load. If distortion is not a significant factor, operation of a driver in the saturation region allows the extension of its capability to much higher drive levels.

SOME PRACTICAL DATA

Driver performance can be accurately specified only when the driver is installed in a well-defined test fixture as described above. This provides excellent information on the driver itself but provides very little information about driver performance in a real application. If the actual application is well-defined, performance data may be used to accurately predict the injected signal and to select the optimum driver for the application. However, the various parameters associated with an application are almost never known accurately, if at all. A typical bulk-injection application generally involves a cable run near an effective ground plane. To show some typical application data, a three-meter length of 1.6 cm diameter rigid copper tubing was suspended about 7 cm above a large ground plane to represent a cable near a ground plane. A length of tubing is used since it represents an ideal cable having both low inductance and low resistance. Also, its rigidity allows simple control of the test geometry. One end of the tubing is terminated in the 0.05-ohm wide bandwidth current viewing resistor used for all of the other data of this article, and the other end is attached to a short to the ground plane. The 4-cm, 3-turn driver characterized in Figures 6a and 7 is placed around the conduit as the drive coupler.

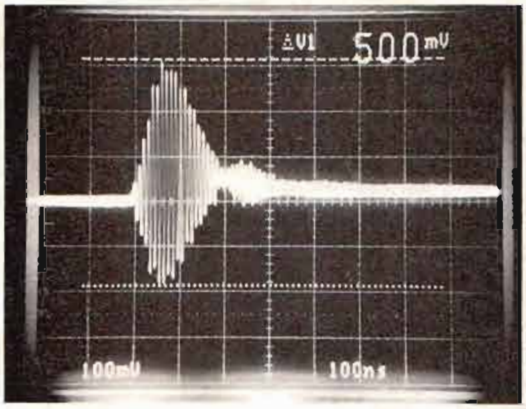
Even with this simple configuration, it is impractical to present in a brief article all the possible data that could be collected. However, a few examples can demonstrate the results to be expected in typical bulk-injection applications. Data are collected at the same three frequencies of Figure 7 earlier to allow simple comparison. The driver is placed at three positions on the copper tubing conductor: at the current measuring CVR, centered on the 3 meter length, and at the shorted end of the conductor (3 m from the point of measurement). The drive level is arbitrarily set at each frequency for 10 A p-p with the driver at the CVR end of the test fixture and is held at the same input level for the other two measurement positions. Figures 13a and 13b show the signal coupled at 10 kHz and 1 MHz respectively. For each of these two frequencies, the signals for a particular frequency is essentially identical for each of the three measurement positions so only one example of each is shown. The injection signal at 10



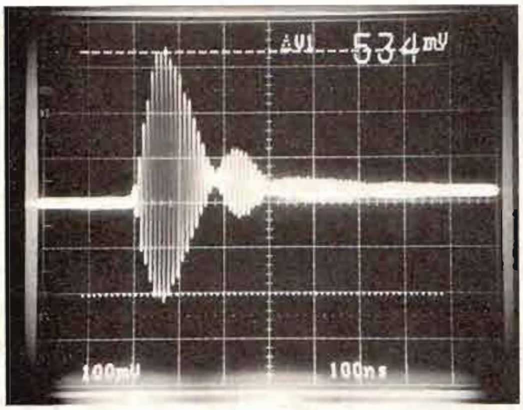
a. 10 kHz

b. 1 MHz

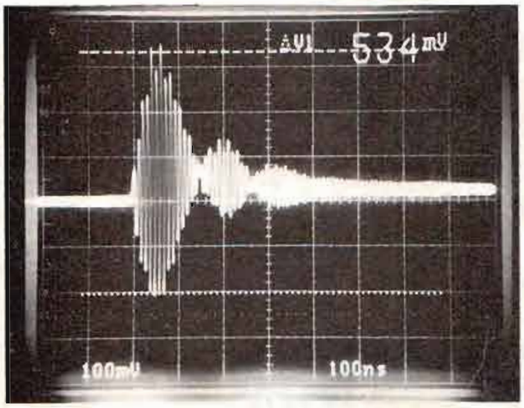
Figure 13. Performance of a 4-cm, 3-Turn Driver Exciting a Simulated Cable Loaded into 0.05 Ohms (0.05-Ohm CVR Potential).



a. Driver Positioned at the CVR



b. Driver 1.5m from CVR



c. Driver at the Shorted Cable End 3m From CVR

Figure 14. Performance of a 4-cm, 3-Turn Driver Exciting a Simulated Cable Loaded Into a 0.05-Ohm Load (0.05-Ohm CVR Potential)

kHz is much similar to those displayed previously for this driver. The 1 MHz signal shows a considerable distortion in the first cycle of the damped sinusoid. This is not seen in the previous response data and is an effect of the application environment (the 3-m "cable"). Figure 14 shows the signal coupled at 100 MHz. Data from each of the three positions is included to show the slight variations with driver position. The damped sinusoid is quite modified in these data. About seven cycles are required for the waveform to "ring up" to the maximum peak level. This is considerably different than the signals of either Figure 7c for this driver with low-impedance loads or 7d with high-impedance loads. For both the 1 MHz and 100 MHz cases, the simulated cable load has a very pronounced effect on the injected waveform. Also, the relatively symmetric wave shape at 100 MHz suggests a relatively high-impedance load as demonstrated in Figure 7d. This suggests that if the maximum drive is to be obtained, a driver with fewer turns may be more effective at the higher frequencies for this "cable".

This demonstrates that even a well-behaved load can cause significant modifications to the injected signal. Real loads, particularly those with nonlinear elements such as potential clamping devices, should be expected to produce much more severe perturbations.

CONCLUSIONS

These examples serve to demonstrate that the magnetic current driver can be a very effective tool in bulk-injection testing applications. However, the configuration of the magnetic driver must be carefully selected if the optimum performance in the bulk-injection testing application is to be obtained with the widely varying loads that are likely to be encountered. The basic versatility of the magnetic driver allows convenient tailoring to specific needs. The ability to alter both its physical and electrical properties allows its optimization to specific applications.

The magnetic current driver is basically a wideband transformer with a primary winding of one or more turns driven by a pulse-power source and a secondary winding of one or more turns formed by the driven cable. Drivers with higher primary-to-secondary turns ratios tend to be more suitable for lower frequency applications and those near 1:1 turns ratios are better candidates for the higher frequencies.

Since no data are typically available defining the various application environments, drivers are most effectively specified when installed in a well-defined test fixture. Such a characterization provides both a reproducible environment for validation and service of the actual driver as well as suitable data to predict driver performance in various applications. This will allow selection of the optimum driver for specific needs.

The actual fidelity of the coupled waveforms will be dependent upon the nature of the actual load. Performance into simple resistive loads may be predicted with reasonable accuracy from bandpass and saturation characteristics. The results with more realistic loads is difficult to predict because of the unknown nature of those loads. With the typical realistic loads of bulk-injection testing, somewhat severe effects on the test waveform should be expected. However, the versatility of the magnetic current driver does allow optimization of the coupling parameters to reduce these effects in specific test applications.■

REFERENCES

1. M. E. Gruchalla, A. J. Bonham and J. L. Gibson, *"Performance of Large Current Drivers,"* 1986 Nuclear Electromagnetic Symposium, Albuquerque, NM, May 1986.
2. M. E. Gruchalla, A. J. Bonham and J. L. Gibson, *"Performance of Linear Amplifier Systems in Direct-Drive Applications,"* 1986 Nuclear Electromagnetic Symposium, Albuquerque, NM, May 1986.

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