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The effects of EMI from cell phones on GMR magnetic recording heads and test equipment ☆

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Abstract

In this work, we study the effects of electromagnetic interference (EMI) on GMR heads and test equipment. It was found that three types of cell phones (AMPS, TDMA and CDMA) did not cause magnetic or resistance change damage to the GMR heads, such as that caused by nearby ESD events. It was also found that EMI from a TDMA cell phone caused errors in a spin stand tester that could disrupt the test process and create yield losses in production. It is concluded that it may be prudent to restrict operation of mobile phones in the immediate proximity of GMR heads during handling and testing. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: ESD; EMI; Giant magnetoresistive heads; Storage; Cellular phone

1. Introduction

It has been shown that electromagnetic interference (EMI) from a remote ESD-induced spark can damage giant magnetoresistive (GMR) heads [1]. In order to be susceptible to damage from EMI, the GMR head needs to be in very close proximity (<30 cm) to a strong ESD source (>500 V) and have additional wires of some length (>10 cm) attached to it in order to create an antenna.

An interesting question is whether the electromagnetic emission from mobile cell phones is also capable of inducing damage to GMR heads. The purpose of this study was to determine whether operation of cell phones in the proximity of the GMR head gimbal assembly (HGA) could damage GMR heads or otherwise influence GMR head testing.

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Various studies analyzed impact of extraneous EMI on GMR heads [2] as well as properties of stress-causing signals [3] with the relation to the head damage.

2. Cell phone overview

There are three basic types of mobile phones in the market:

2.1. Analog (AMPS)

This technology is largely obsolete. It is still popular due to the huge installed base. Many digital phones have back-up analog mode to compensate for diminishing lack of coverage for digital service. AMPS provides continuous transmission of a signal in 800 MHz band.

2.2. TDMA

Phones made to this standard transmit digitized voice in packets in controlled time intervals (time domain multiplex access). Typical duration of the transmission pulse burst is 577 μs and the dwell time is 4.6 ms. One of the variations of TDMA–GSM is the most popular type of phone in the world. It is used almost exclusively in Europe and in many countries in Asia. TDMA phones work in two basic frequency bands 800/900 and 1800/1900 MHz.

2.3. CDMA

CDMA stands for Code Division Multiplex Access and is the most recent standard developed by Qualcomm. It relies on mathematical decoding of many signals coming to the receiver at the same time at the same frequency. Each signal is spread over many frequencies using a special type of encoding. Since CDMA requires very tight control of the signal power, the farther away the phone is from the base station the higher is its transmission power. If the phone is located near the base station, then its transmitting power may be negligible.

The CDMA phones typically transmit at $\sim$800 MHz. They are popular in the US and some countries in Asia (China, Korea, etc.). The next generation of mobile phones, called 3G, is just appearing in the market and will most likely rely on a combination of CDMA and TDMA technologies.

The assumption is that higher the frequency, more the GMR head is susceptible to the radiation due to better antenna matching. Since there are many factors influencing the possible damage to the GMR head, this assumption has to be tested.

3. Discussion of electromagnetic emission and GMR heads

Most studies on damage to GMR heads were done using a metal-contact ESD event as the source. Mobile phones, as well as the other EMI-related sources, represent more of a continuous wave or packet-type signal rather than an extremely short ESD transient. In order to understand the effect of such a signal on the GMR head, let us examine the physics of damage.

Electromagnetic radiation generates electric voltages and currents in any conductive objects which act as antennae. The GMR head assembly is also an antenna. Each antenna has its resonance frequency at which the electric signal caused by EM field is the highest. The resonance frequency is determined largely by the size and the geometry of an antenna. The same GMR head assembly configured differently or connected to a test or an assembly fixture differently may have different resonant frequencies. An ESD event has extremely wide bandwidth due to its very short duration. Therefore, almost any antenna configuration will be able to pick up some signal. For a harmonic signal such as the one produced by a mobile phone, a GMR head assembly tuned "by accident" to the right frequency may be able to generate a very substantial signal even from a medium-level field.

Fig. 1 represents the thermal balance of GMR head exposed to an electromagnetic field. As seen, the energy from EM field enters the GMR head via induction of voltage and currents. The electromagnetic field generates energy that heats up the GMR sensor. There are only several known ways for this energy to exit the GMR head assembly: convection, radiation and conduction.

1. *Convection*: heated object heats immediate layers of air, which rises and takes away the heat. Convection is widely used for heating rooms, etc. However, convection is a very slow and inefficient way of exchanging heat and is not a major contributor here.
2. *Radiation*: thermal radiation takes away heat from the heated object by emitting infrared radiation. Since the surface area of the GMR head is very small and the surface emissivity is low (GMR head assembly is highly reflective and does not have properties of an ideal "black body"), radiation is also not a major contributor in our case.
3. *Conduction*: heat escapes GMR head assembly via wires attached to the head assembly. Wires can conduct heat efficiently and conductivity can be a significant

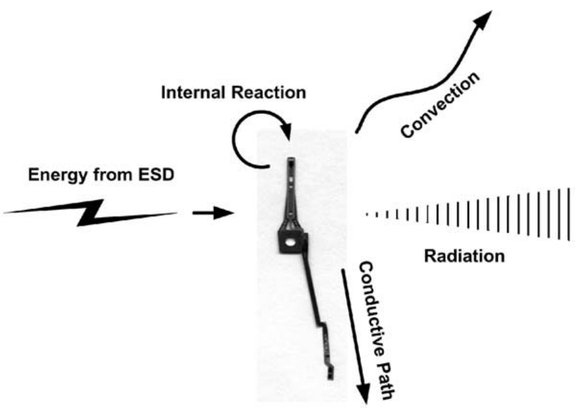

Fig. 1. GMR thermal balance.

contributor to heat exchange. If the heat induced into GMR head cannot escape fast enough, it raises the temperature of the GMR head and may lead to its eventual melting. This melting is a phase change (solid to liquid) that absorbs thermal energy very efficiently.

If the energy being supplied to the GMR head arrives too fast in large doses, not enough of it can escape via conventional routes and most of that energy ends up as a contributor to melting the GMR head. Therefore, power (energy/time) of the incoming energy which is the most important factor in mechanism of damage to GMR head.

Unlike ESD events, emission from mobile phones and other EMI-related sources comes in on a continuous basis. At some point, the temperature of GMR head assembly exposed to such radiation will reach equilibrium. If the point of this equilibrium is high enough to induce melting of the GMR head then damage will occur. If the sensor temperature reached at equilibrium is above the critical magnetic ($\sim 300^\circ$C) or melting ($\sim 1000^\circ$C) temperatures, then the GMR sensor will be damaged.

4. Source assessment

Table 1 lists the equipment used for source assessment. The measurements were done using LeCroy oscilloscope and CTS001 antenna with the output of –18.5 dBm or 26.6 mV RMS at 1 V/m. The approximate distance between the source and the antenna was 3″.

The waveforms of electromagnetic field generated by these sources are shown in Figs. 2–7. These measurements show that the field strength from the mobile phone is

Table 1
List of measurement equipment, RF and ESD sources and head type used in this study

Measurement equipment	LeCroy oscilloscope model 9362. HP (Agilent) spectrum analyzer model HP8595A. Credence technologies' EMI/ESD diagnostics kit CTK053 with CTS001 calibrated broadband active antenna. Credence technologies' EM eye CTM045 field strength meter. Credence technologies' EM aware ESD event monitor CTC034 with local and remote antenna CTC113.
RF emission sources	Motorola 845 MHz CDMA phone. Nokia 6162 800 MHz TDMA phone. Motorola 830 MHz AMPS phone.
ESD sources	Bag of SMA RF connectors. Plastic tube with two metal cylinders. Barbecue lighter (drug store issue).
GMR test equipment	QST Tester model integral solutions international 2001 (resistance and amplitude measured).
GMR heads	5 Gb/in^2 PtMn GMR heads used in this study. 30 V_{HBM} magnetic failure level.

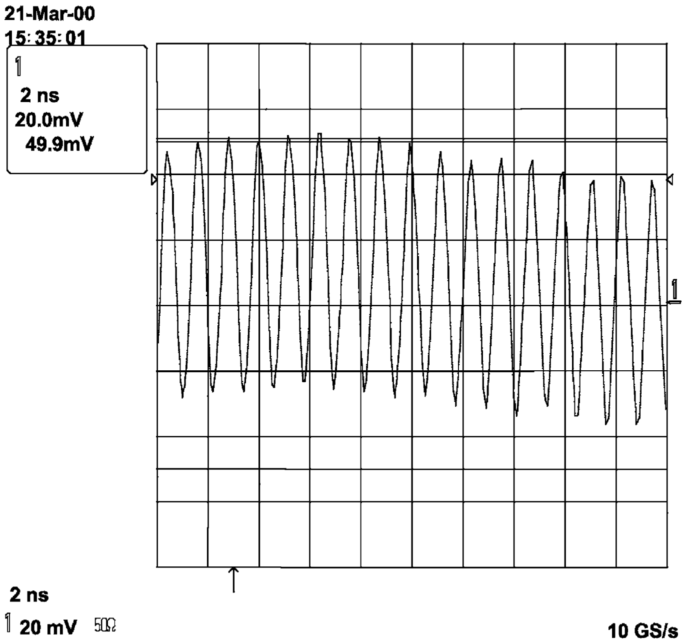

Fig. 2. Waveform from AMPS phone.

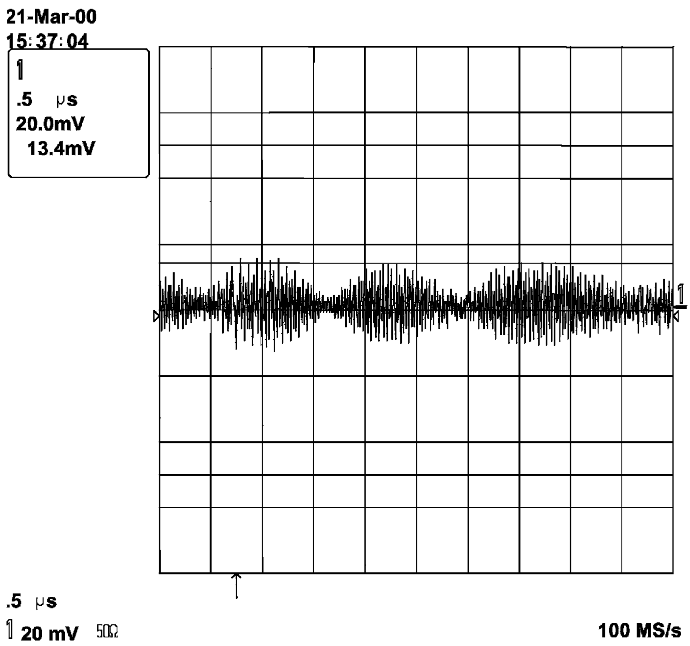

Fig. 3. Waveform from CDMA phone.

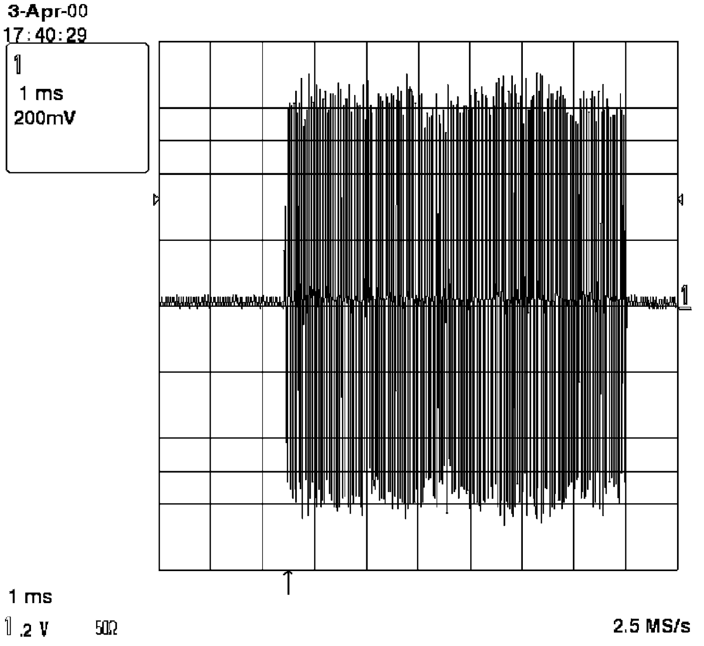

Fig. 4. Waveform from TDMA phone.

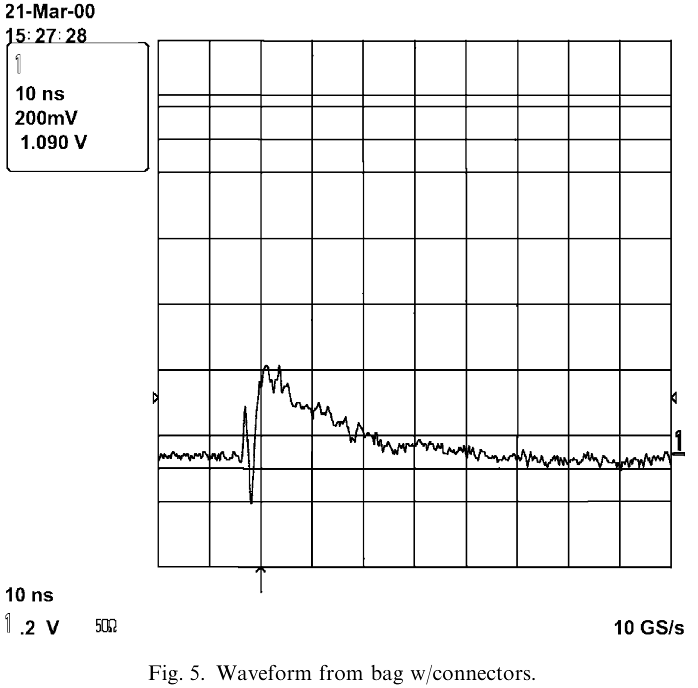

Fig. 5. Waveform from bag w/connectors.

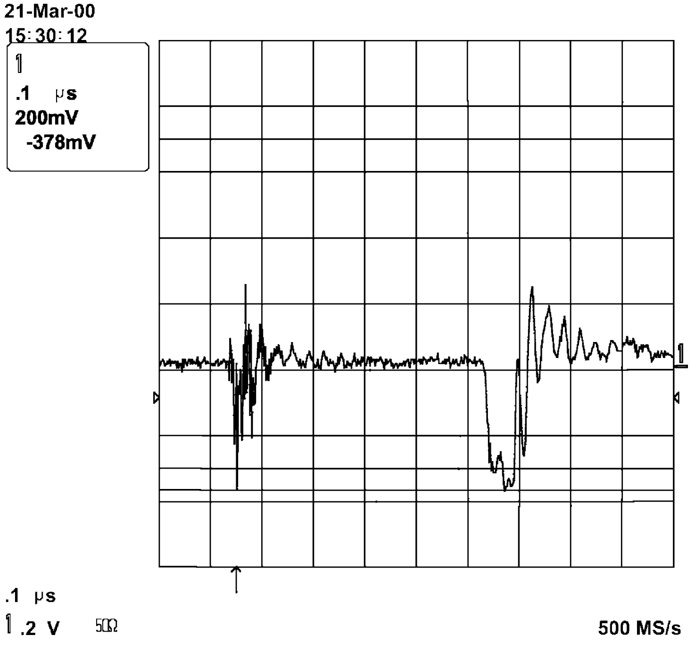

Fig. 6. Waveform from barbecue lighter.

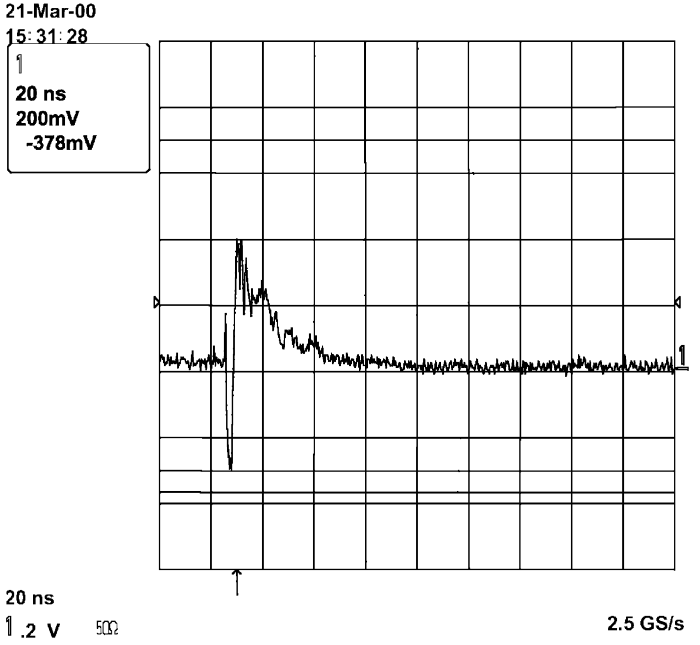

Fig. 7. Waveform from tube w/cylinders.

$\sim$7 to 10 times *less* than that generated by an ESD event shown to be damaging to GMR heads during the experiments.

This is, however, by itself not an indication that it may induce 10 times less the damage. The emission from the mobile phones, for example, lasts longer that an ESD event and may result in more heat into GMR head than the stronger ESD event. Also, measurement uncertainties may introduce substantial error in measurements. The ratio of 7–10, though comforting, does not yet present convincing hard evidence by itself that the emission from mobile phones is negligible for the purposes of investigation.

5. Experimental

Phase 1. Source assessment

1. To identify mobile telephone technologies
2. To measure field strength and other properties of the electromagnetic fields generated by controlled ESD events and selected emission sources

Phase 2. Exposure of GMR HGA to emission

The GMR heads were exposed to electromagnetic fields under controlled conditions and tested for damage. The HGA was exposed to emissions from nearby ESD events under the same circumstances.

6. Disclaimer

The tests performed at this stage were done under imperfect quantitative conditions. The distance between the sources, measurement antennae and GMR heads, as well as the mutual orientation of devices was not tightly controlled. This results in more qualitative than quantitative results.

Field strength was assessed based on the calibration data of measurement antennae. Electromagnetic field measurements in principle are subject to uncertainty. According to established norms, the inherent uncertainty in measurements is $\pm 2.4\,\text{dB}$ even if the measurement equipment is calibrated. In addition, such parameters as reflections, standing waves, antenna orientation, the geometry of radiating sources and other environmental variances heavily contribute to the errors in measurements.

No two ESD events are alike. Specific measured ESD events may vary between seemingly similar. Statistics need to be gathered to gain a level of comfort in measuring field strength from ESD events.

The mobile phone transmission varies with the circumstances. The measurement of emission from mobile phones must be repeated several times under the same and under different conditions in order to assure that error is minimized.

It is also important to note that measurements of a CDMA signal require a special setup (i.e. bandwidth envelope, proper detector, etc.) and cannot be performed with any degree of accuracy on equipment not specially designed for that purpose.

Some measurements were repeated for verification using different types of equipment, such as:

(a) antenna and oscilloscope,
(b) antenna and spectrum analyzer,
(c) EM eye field strength meter

The results correlated reasonably well.

7. Test arrangement

Three setups were used for assessment of damage to the GMR heads. The first setup (see Figs. 8–10) had a GMR head in a special fixture that allowed connection of various types of antennae. Different types of antennae were connected to the GMR head via a special adapter that allowed connection of a differential-signal antenna to the GMR head. The field strength of ESD events was measured with CTS001 antenna placed in small non-metallic vise, CTA225C interface module and LeCroy oscilloscope (both are not shown). EM aware ESD event monitor CTC034 placed near the setup as shown monitored ESD events. Each GMR head used for the experiment was tested on the QST to establish resistance and magnetic performance. After each exposure to EMI, the GMR head was tested again on the QST again. Several different antennae, i.e. telescopic monopole and loop, as well as no antenna were utilized.

Fig. 11 shows the second setup, which involved a GMR head on a quasistatic (QST) tester. No external antenna was used in this setup. A source of

Fig. 8. Stand-alone setup w/loop antenna.

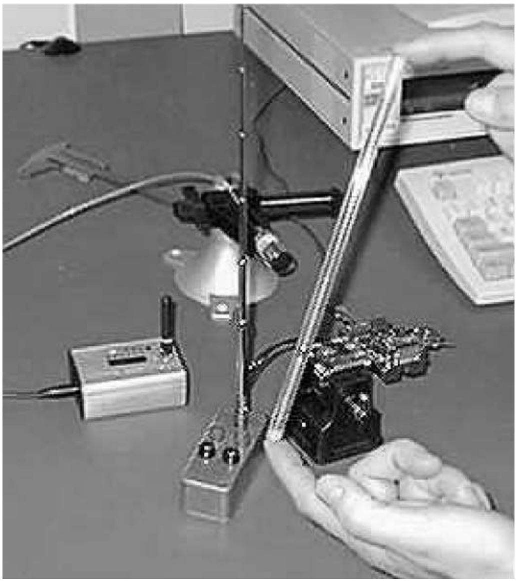

Fig. 9. Monopole antenna setup.

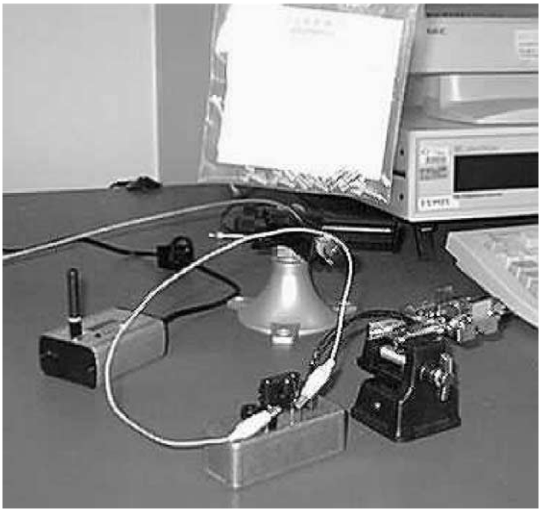

Fig. 10. ESD source and loop antenna.

electromagnetic emission was brought as close as possible to the GMR head without making a contact. The third setup dealt with a GMR head in the Guzik tester prior to the test while the test was in progress (Fig. 12). In this setup, performance of GMR head was verified using spin stand measurements.

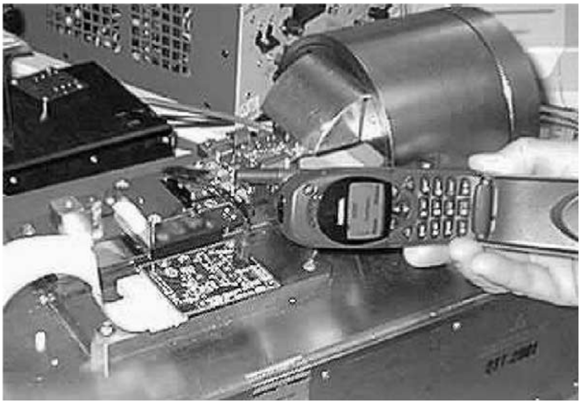

Fig. 11. Setup in QST.

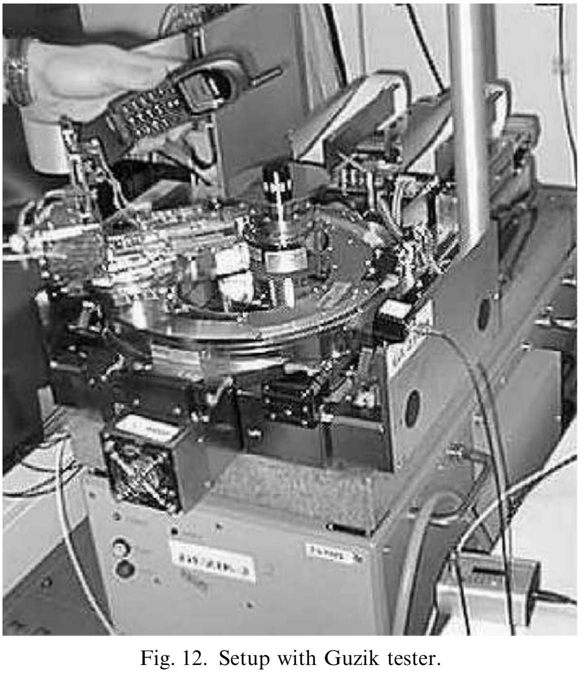

Fig. 12. Setup with Guzik tester.

8. Results and discussion

8.1. Experiment 1: GMR assembly with no antenna

8.1.1. Test A

No antenna was connected to the terminals of the GMR assembly and the test fixture was grounded. Three types of mobile phones were brought close to the antenna and to the head itself, connection was established and the electromagnetic field was monitored. The GMR fixture was tested both grounded and ungrounded. No change in the parameters of GMR heads was observed.

As a reference, a bag of RF connectors was intensely shaken at the same proximity to the antenna. No change in GMR head performance was observed as well. The same test was performed with test fixture ungrounded with identical results.

8.2. Experiment 2: GMR assembly with monopole antenna

EMI in this setup injected an induced voltage into one of the leads of GMR head, creating a differential voltage across it.

8.2.1. Test B

A telescopic monopole antenna extended to 11 cm was connected to one of the terminals of GMR assembly as shown in Fig. 9. Three types of mobile phones were brought close to that antenna and to the head itself, connection was established and the electromagnetic field was monitored. The GMR fixture was tested both grounded and non-grounded. No change in parameters of GMR heads was observed.

As a reference, a bag of RF connectors was intensely shaken at the same proximity to the antenna. No change in GMR head performance was observed as well. The same test was performed with test fixture ungrounded with identical results.

8.2.2. Test C

A telescopic antenna was extended to 30 cm. All the above experiments were repeated. No changes were observed when mobile phones were brought close to either the antenna or to the head itself. However, when the telescopic antenna was exposed to the electromagnetic emission from the ESD from the tube with two metal cylinders under the same conditions and the head opened with a resistance $>40\,\mathrm{M\Omega}$.

8.3. Experiment 3: GMR assembly with loop antenna

This setup (Figs. 8 and 10) injected current into the GMR head.

8.3.1. Test D

A 6″ (150 mm) diameter single-loop antenna was connected across terminals of the GMR HGA. Three types of mobile phones were brought close to that antenna and to the head itself, connection was established and the electromagnetic field was monitored. No change in parameters of GMR heads was observed.

A bag with RF connectors was vigorously shaken in the proximity of the loop with no adverse effect to the GMR head. However, when exposed to the emission from the plastic tube with two metal cylinders, the GMR head open circuit failed.

8.3.2. Test E

A two-turn 2.75″ (70 mm) diameter loop antenna was connected across terminals of the GMR HGA. Three types of mobile phones were brought close to that antenna and to the head itself, connection was established and the electromagnetic field was monitored. No change in parameters of GMR heads was observed. A bag with RF connectors was vigorously shaken in the proximity of the loop. The GMR head opened (high resistance) and failed.

8.4. Experiment 4: GMR assembly mounted on a QST tester

8.4.1. Test F

A GMR HGA was mounted on QST. It was exposed to emission to all three mobile phones and to both sources of non-contact ESD events. No damage occurred. QST tester apparently provides sufficient shielding for GMR head.

8.5. Experiment 5: GMR assembly mounted on the Guzik tester

8.5.1. Test G

A GMR HGA was mounted on Guzik tester as shown in Fig. 12. The GMR HGA was exposed to emission to all three mobile phones and to both sources of non-contact ESD events both before and during the test. The GMR head was undamaged. However, when exposed to emission TDMA phone at a distance of 4″ (10 cm) from the test fixture, Guzik tester reported the error "Signal unstable during main gain adjustment". Apparently, the TDMA phone induced sufficiently high signals into the test circuit to influence the measured signal to the degree that the tester recognized it as an error. Since neither AMPS nor CDMA phone was able to produce the same effect, it is our assumption that the pulsed nature of TDMA

Table 2
Summary of all test results. Comments in bold show changes caused by EMI

Test setup	Mobile phones	ESD source
GMR HGA with no antenna connected.	All models: no damage.	All types: no damage.
GMR HGA with 11 cm monopole antenna connected to one end.	All models: no damage.	All types: no damage.
GMR HGA with 30 cm monopole antenna connected to one end.	All models: no damage.	Plastic bag w/connectors: fatal damage—open.
GMR HGA mounted on QST.	All models: no damage.	All types: no damage.
GMR HGA with single loop antenna 6″ (150 mm) diameter.	All models: no damage.	Plastic bag w/connectors: no damage plastic rod w/cylinders: fatal damage—open.
GMR HGA with double loop antenna 2.75″ (70 mm) diameter.	All models: no damage.	Plastic bag w/connectors: fatal damage—open.
GMR HGA mounted on Guzik tester.	All models: no damage TDMA phone: tester error: "error 2034: signal unstable during main gain adjustment".	All types: no damage parametric test errors on Guzik tester.

Table 3
Summary of amplitude (TAA), asymmetry (TAAA) and stability (COV) during

	LF TAA (mV)	TAAA (%)	COV (TAA) (%)	COV (TAAA) (%)
Initial 1	0.96	13.75	1.04	2.62
Initial 2	0.97	12.71	0.74	2.37
After AMPS phone	0.96	14.30	0.96	2.46
AMPS during test	0.96	13.03	0.89	2.82
CDMA during test	0.97	14.18	0.93	2.66
After ESD bag	0.96	13.79	0.91	2.57
ESD bag during test	0.96	13.65	0.89	2.76
After ESD rod	0.96	14.50	0.99	2.44
ESD rod during test	0.97	13.11	1.57	56.58
TDMA during test	0.96	13.08	1.26	3.99

signal was a deciding factor in generating the error. To the credit of Guzik tester, it was possible to recognize the error and to inform the operator.

Table 2 summarizes all the changes observed during Guzik testing, i.e. that EMI from ESD caused by the sliding rod, and from TDMA phone, was interpreted by the Guzik tester as changes in some of the head parameters. However, when EMI condition was removed, measured parameters of GMR head were within the norm. Table 3 summarizes the results from all the tests.

9. Conclusions

These limited tests showed that under certain test conditions, cell phones did not inflict damage to GMR heads. Remote ESD events, however, were capable of damaging GMR heads. A relatively small safety margin, about a factor of 10, was found to exist between the field strength from the mobile phones and from the ESD events capable of damaging GMR heads. Although ratio of 10 in field strength commands ratio of 100 in generated energy under identical circumstances, large variations in electromagnetic field strength exist due to proximity, reflections, standing waves, variations in phone emission and a multitude of other factors. Therefore, the conclusion that it is *completely* safe to operate a mobile phone in the environment where GMR heads are handled cannot be drawn.

Electromagnetic interference caused by the mobile phones (as well as by the ESD sources) caused errors in test equipment that disrupted the test process and would have created losses in production. As an example, debugging of the error message on Guzik tester can take a long time and possibly stop production. Perceived parametric failures of the GMR head would also cause losses due to discarded heads that are completely normal. It is concluded that it may be a prudent practice not to allow operation of mobile phones in the immediate proximity of areas where GMR heads are handled.

Acknowledgements

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