Pump up the volume! Supercapacitors enhance audio quality and power in mobile phones

As multimedia and music phones grow in popularity, consumers want an iPod-quality audio experience without the buzzing and distortion associated with wireless transmissions.

This article describes the problems delivering high power and high quality audio in music-enabled mobile phones, and how a supercapacitor can overcome them. This same supercapacitor can also enable high-power LED Flash photography without compromising the handset's thin profile, as described in a previous article, http://www.powermanagementdesignline.com/showArticle.jhtml?printableArticle=true&articleId=188100789

Before outlining the problems, I'll describe a supercapacitor and its overall role in power management. Supercapacitors bridge the power gap between batteries and conventional capacitors, delivering higher power bursts than batteries and storing more energy than capacitors. Supercapacitors provide the power bursts needed for peak power events – GSM/GPRS RF transmission bursts, GPS readings, music, flash photos and video – then recharge from a battery. Benefits include improved talk time, longer battery life, a brighter flash and better audio. Designers also save space and cost because they can size the battery and power circuitry to cover average power consumption rather than peak loads.

Audio quality and power issues in current music-phone designs

Today's mobile phones typically use class D audio amplifiers. These use 2 pairs of FETs in an H-bridge to control the speaker coil. The configuration is shown in Fig 1. Q1 & Q4 ON with Q2 & Q3 OFF drive the speaker coil in one direction, while Q1 & Q4 OFF with Q2 & Q3 ON drive the coil in the opposite direction. The power supply for this arrangement is typically the battery which is ~3.6V. A mobile phone with stereo audio will have a pair of amplifiers and speakers. For an 8Ω speaker the maximum audio power = $3.6V^2/8\Omega$ = 1.6W, or 3.2W for a stereo pair. The battery current for peak stereo audio power = 3.2W/3.6V = 0.9A. This arrangement results in an audio playback capability which can suffer from power limitations, distortion and interference.

Problem 1: The battery is unable to supply the simultaneous peak power demands of wireless data transmissions and the audio amplifier, resulting in distortion.

In a GSM/GPRS/EDGE phone, the battery will not be able to supply both the peak audio current and the peak RF transmit power for a response to a network poll while the user is listening to music. Networks periodically poll a mobile phone to keep track of which cell it's in, and to determine the transmit power the phone should use. During such a network poll, the audio amp supply may droop as the phone responds, which sounds as a "click" to the user. The battery, however, is easily capable of supplying the average audio current which is approximately 100mA – 200mA.

Problem 2: Audio noise/buzzing results from peak battery currents in excess of 1A, which cause significant ripple in the audio amplifier supply voltage.

If the battery pack + connector + PCB trace total impedance = 150mΩ, then a 1A peak will result in a 150mV ripple in the supply voltage, while a 1.8A peak will cause a 270mV ripple. The user hears this ripple in the supply voltage as noise in the audio. GSM/GPRS/EDGE transmissions, with peak currents of 1.8A, will also cause audio noise which the user may hear as a 217Hz buzz during a phone call.

Problem 3: Limited audio power and poor bass response in CDMA, GSM & 3G phones.

The audio capability and quality of all mobile phones, irrespective of their type, depends on the power output of the audio amplifiers and the impedance of the speakers. In a typical set-up where two class D amplifiers operate off a 3.6V power supply from the battery to drive a pair of 8Ω speakers, the maximum audio power is 3.2W, and peak battery current is 0.9A as outlined above. The result is thin, low-power audio performance, with a very limited bass response, whether delivered through the phone's internal speaker or through externally attached speakers/headphones.

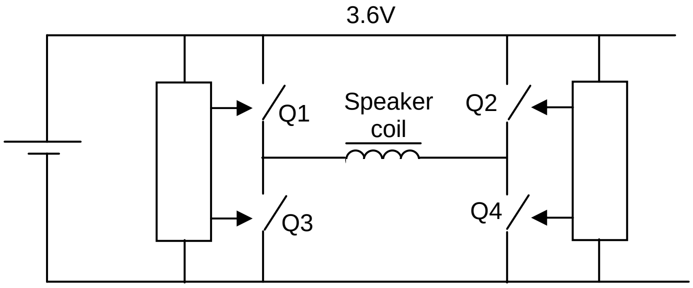

Fig 1: Typical configuration for class D amplifier

Improved music-phone design with a supercapacitor

Fig 2 shows an alternative arrangement using a supercapacitor which solves all the issues outlined above, and quadruples the peak audio power. A 0.55F, 85mΩ dual-cell supercapacitor such as the CAP-XX HS206 provides the peak power, while the battery supplies the average power. The boost converter charges the supercapacitor to 5V. Results:

1. Peak power for a stereo phone increases to 2 x $5V^2/8\Omega$ = 6.25W or approximately double the power of the case above. Also, because the supercapacitor can supply very high peak currents, designers can use 4Ω speakers, increasing peak audio power to 12.5W, or 4 x the original power.
2. A 0.55F, 85mΩ supercapacitor will have only a 200mV ripple after supplying peak power of 12.5W for 10msec with a peak battery contribution of 1.8W (0.5A @ 3.6V).
3. The battery – which now only supplies an average audio current of 150 – 300mA to recharge the supercapacitor – can also supply peak RF power for a network poll response without compromising audio power, so there are no "clicks" while responding to network polls.
4. Further, any ripple at the battery voltage due to RF transmission is not reflected at the audio amp. This ripple is filtered by the line regulation of the boost converter and the supercapacitor, eliminating any 217Hz buzz.

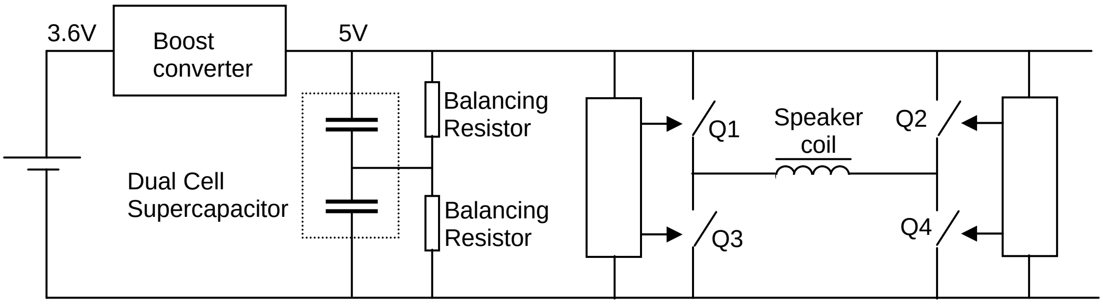

Fig 2: Class D amplifier with supercapacitor

Test Results
To test the audio improvement with a supercapacitor we created two test setups:

Test Setup 1: Class D Audio Amps
In the first test setup we built the circuits as shown in Fig 1 & in Fig 2, using a pair of TPA2023D1 to provide the stereo audio channels:

1. For the case without supercapacitor (Fig 1), we connected the audio amps to a Li Ion battery @ 3.7V and drove a pair of 8Ω speakers.
2. For the case with supercapacitor (Fig 2), we connected the battery to the input of a buck-boost converter, with input current limited to 250mA and with the output set to 5V. We placed a 0.55F supercapacitor with 85mΩ ESR across the output of the buck-boost and connected it to supply inputs of the audio amps as shown in Fig 2. We also drove 2 pairs of 8Ω speakers, 1 pair across each audio amp, halving the output impedance and further doubling the total speaker power.

With this setup, we tested:

1. High power bass bursts representing a bass beat and
2. A network poll while listening to music, which we represented as a 1KHz tone, in order to make any improvements from the supercapacitor obvious. The speaker power in Figs 3 – 6 is the total speaker power for both stereo channels.

Bass Beat
We created a 100Hz bass beat that lasted approximately 120msecs and repeated every 0.5secs. Fig 3 shows speaker power and battery current for the standard configuration of most cell phones, and Fig 4 shows the same information for the configuration with a supercapacitor and 4 speakers. Table 1 below compares peak currents and power for the two cases. In Table 1, Speaker Power refers to the total power of all speakers in the system, i.e. 2 speakers for the first case and 4 speakers in the second case.

Table 1

	Standard mobile phone setup without supercapacitor	**Mobile phone setup with Supercapacitor**
Peak Battery Current	0.56A	0.261A
Average Battery Current	0.084A	0.253A
Peak Speaker Power	**1.65W**	**5.2W**
Average Speaker Power	0.211W	0.67W
Crest Factor	7.82	7.76
RMS Battery Power	0.64W	0.96W
RMS Speaker Power	0.50W	1.60W
Battery energy in 1 period	0.160J	0.48J
Speaker energy in 1 period	0.105J	0.34J
Efficiency	65%	70%

We set the input signal amplitude to the audio amps in both cases to the maximum just before the output starts to clip. This means we increased the amplitude in the second case compared to the first, to take advantage of the increase in the audio amp power supply from 3.7V to 5V.

Key points to note are:

– With the supercapacitor in circuit, the battery current is limited at the input to the boost converter. This means that the peak battery current with supercapacitor is only 47% of what it was without the supercapacitor while total peak speaker power with supercapacitor has increased by 3.15 times.

– Increased switching losses at higher currents and the amplifier not working right to the rail due to the supercapacitor ESR and audio amp FETs' R_{DSON} explain why we achieved a three-fold rather than four-fold increase in peak audio power.

– The three-fold increase in speaker power during bass bursts makes music sound much "fuller".

– The root mean square calculation gives much greater weight to peaks. Since the peak battery power is limited by the 250mA input current limit in the supercapacitor case, the accurate way to compare efficiency is to measure the total battery energy and total speaker energy during 1 period of the test waveform.

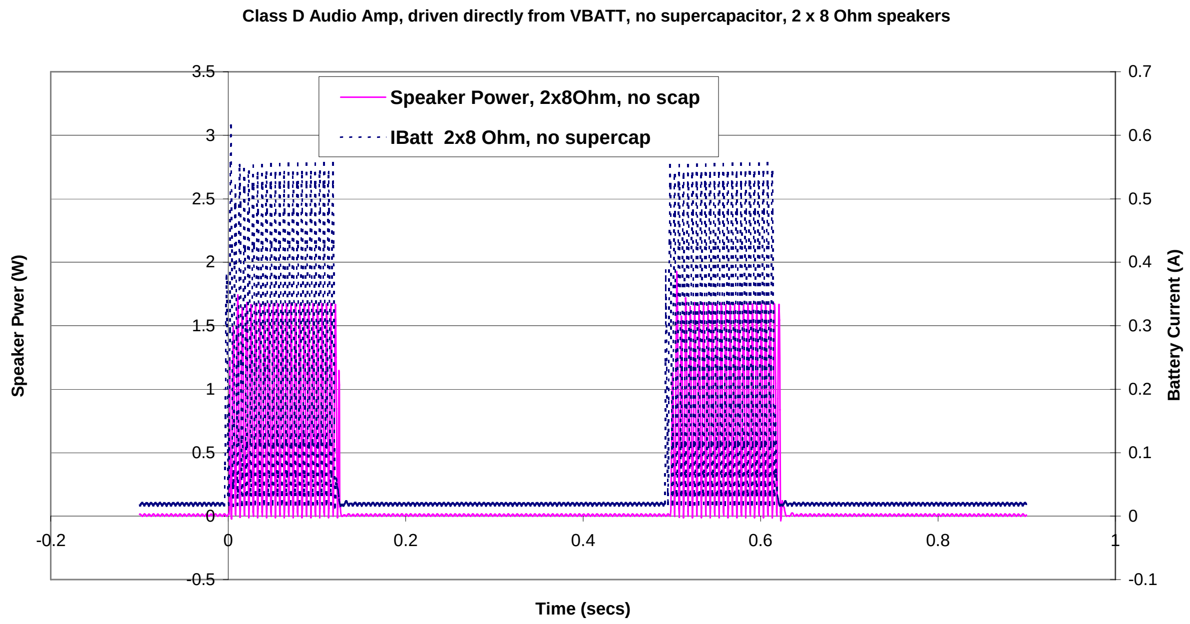

Fig 3: Bass beat, no supercapacitor

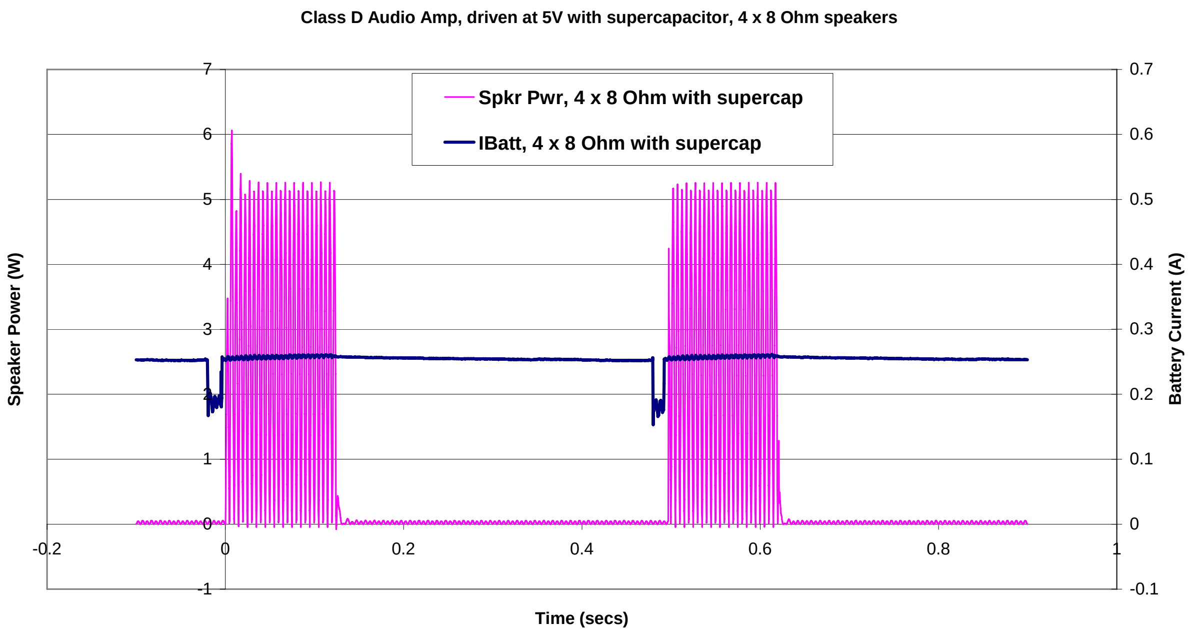

Fig 4: Bass beat with supercapacitor

Network Poll

We simulated the effect of a GSM/GPRS/EDGE network poll while listening to music by applying a 2A, 1.15ms pulse while the audio amp was playing a 1KHz tone at maximum amplitude. Fig 5 shows what happened with the standard circuit. The battery current increased to ~2A, causing the battery voltage to drop. The droop in the audio amplifier supply voltage caused the sine wave to clip - the distortion in the sine wave is clear in Fig 5. This is heard as a “clicking” sound.

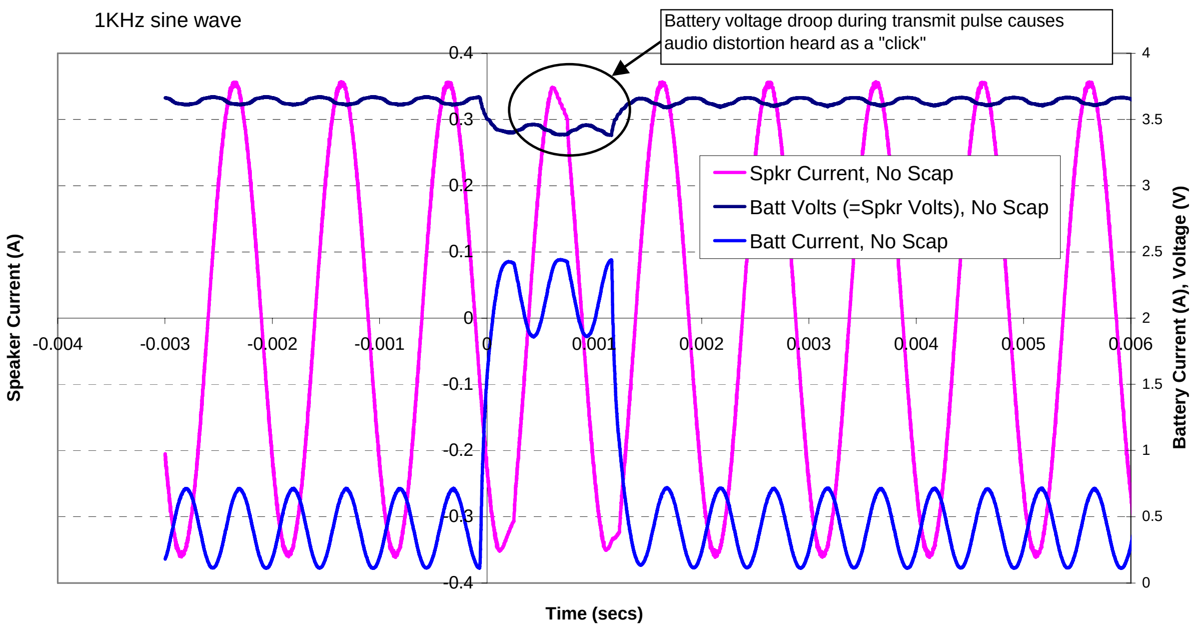

Fig 5: Distortion in audio when battery needs to supply peak current for audio + RF PA.

Fig 6 shows what happens when the supercapacitor supplies the audio amplifier power. The audio amp supply is now 5V, up from 3.6V without a supercapacitor as shown in Fig 5.

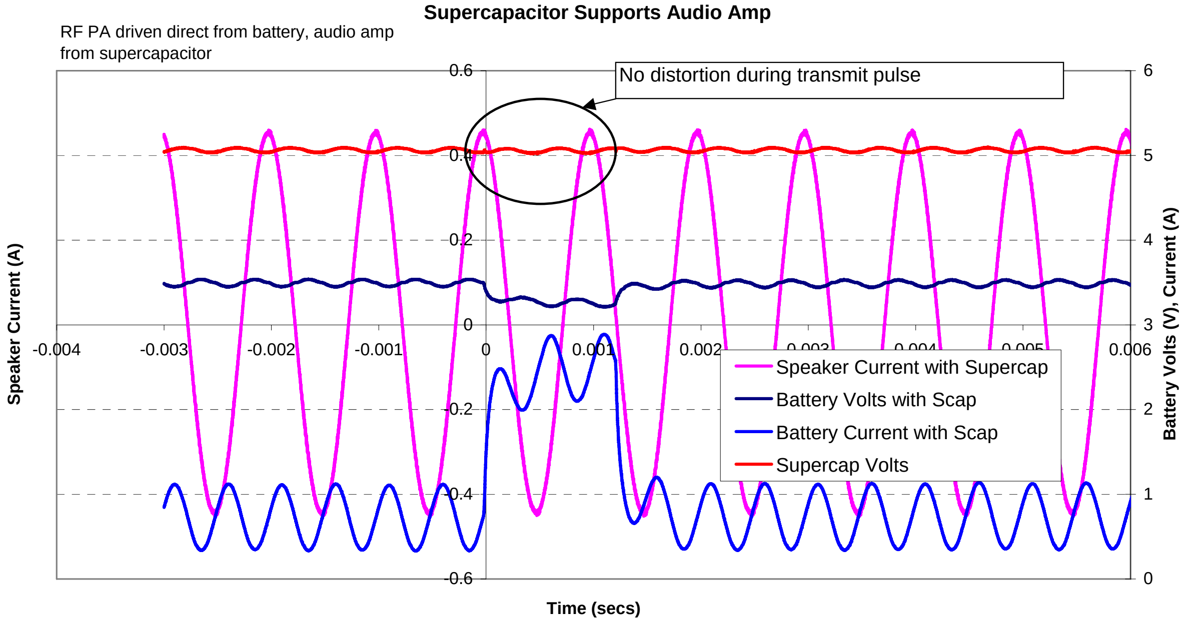

Fig 6: Supercapacitor buffers the audio amp from battery voltage droop during the RF transmit pulse, so there is no audio distortion

Accordingly, we have increased the volume of the 1KHz sine wave. Note that the peak speaker current has increased from 0.35A in Fig 5 to 0.45A in Fig 6. Hence peak speaker power with supercapacitor = 0.45A x 5V = 2.25W compared with 0.35A x 3.6V = 1.26W without supercapacitor, or an increase of ~80%. Fig 6 shows that when the battery current increases to >2A to supply the RF transmit pulse, the supercapacitor voltage is unaffected – the supercapacitor has enough energy storage, or capacitance, to keep supplying the audio amp while there is a drop in power received from the battery. This means the 1Khz tone does not suffer any distortion during the RF pulse. The boost converter shown in Fig 6 limits the battery current supplied to the supercapacitor to 250mA.

Test Setup 2: SonyEricsson MPS60 External Audio Amp & Speakers

To test performance with a real case listening to music, we modified a set of MPS60 speakers , which plug into typical SonyEricsson phones such as the K750,. The dongle, which plugs into the base of the phone, contains a class AB audio amp powered solely by the phone, with the supply pin connected directly to the battery (Vbat). Before modification, the audio amp drives 2 x 8Ω speakers.

1. Shown in Fig 7 below, we modified the dongle to include a boost converter and supercapacitor, as illustrated in Fig 2. The supercapacitor was charged to 5V and we connected the audio amp supply pin to the supercapacitor. This increased the audio amp supply voltage from ~3.6V = Vbat to 5V.
2. Having increased the audio amp supply voltage we then doubled the gain of the audio amp. This approximately doubles the audio power.
3. Since the supercapacitor can deliver very high peak currents, we also connected a second pair of 8Ω speakers across the output of the audio amp (shown in Fig 8 below), effectively driving 2 x 4Ω speakers. This doubles audio power again.
4. Finally, including the supercapacitor to stiffen the audio rail also allowed us to remove three electrolytic capacitors, as shown in Fig 7.

Figures 9 & 10 compare battery current and speaker power between the standard set of speakers and our modified set for a piece of music.

Fig 7: External audio amplifier, powered from the phone, modified to include a supercapacitor

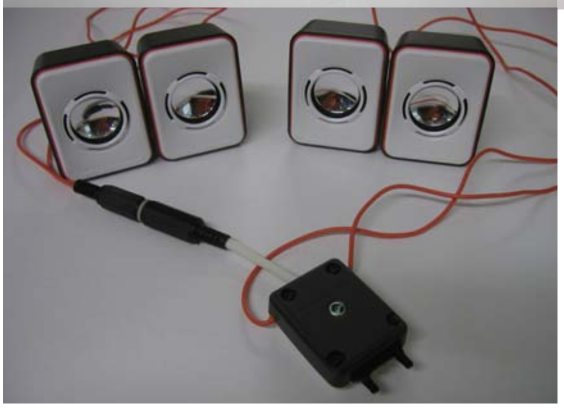

Fig 8: Modified external speaker set including a second pair of speakers connected in parallel to the original pair.

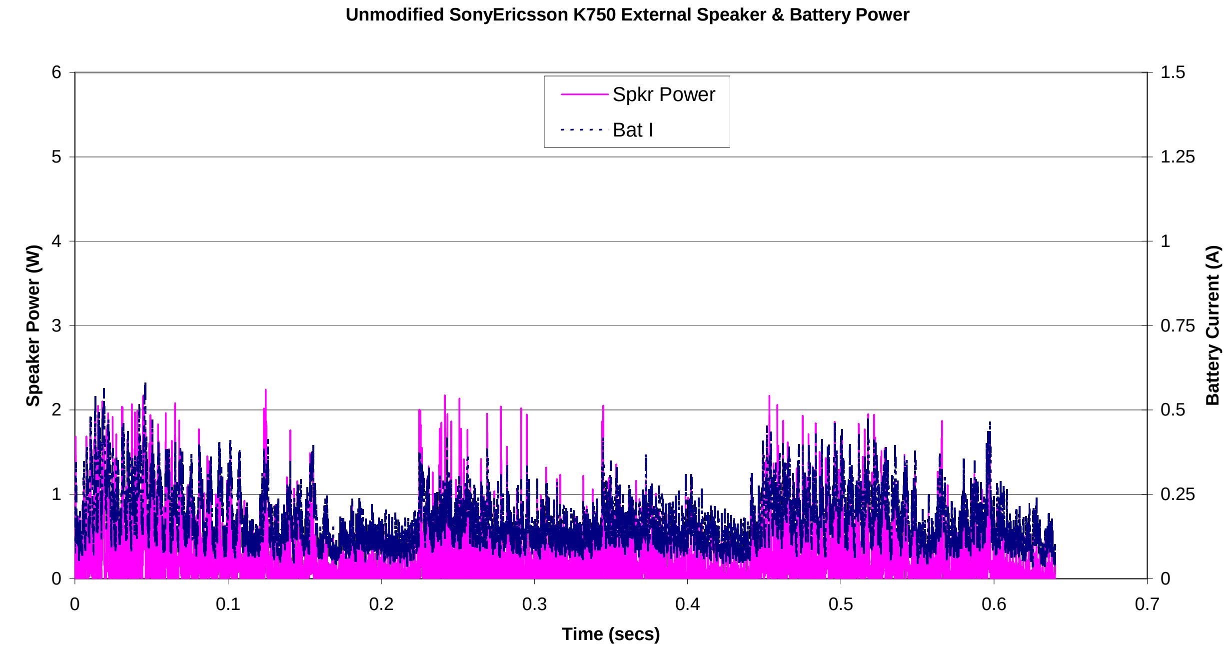

Fig 9: Battery current and speaker power while playing music, standard setup driving 2 x 8Ω speakers with audio amp powered from Vbatt.

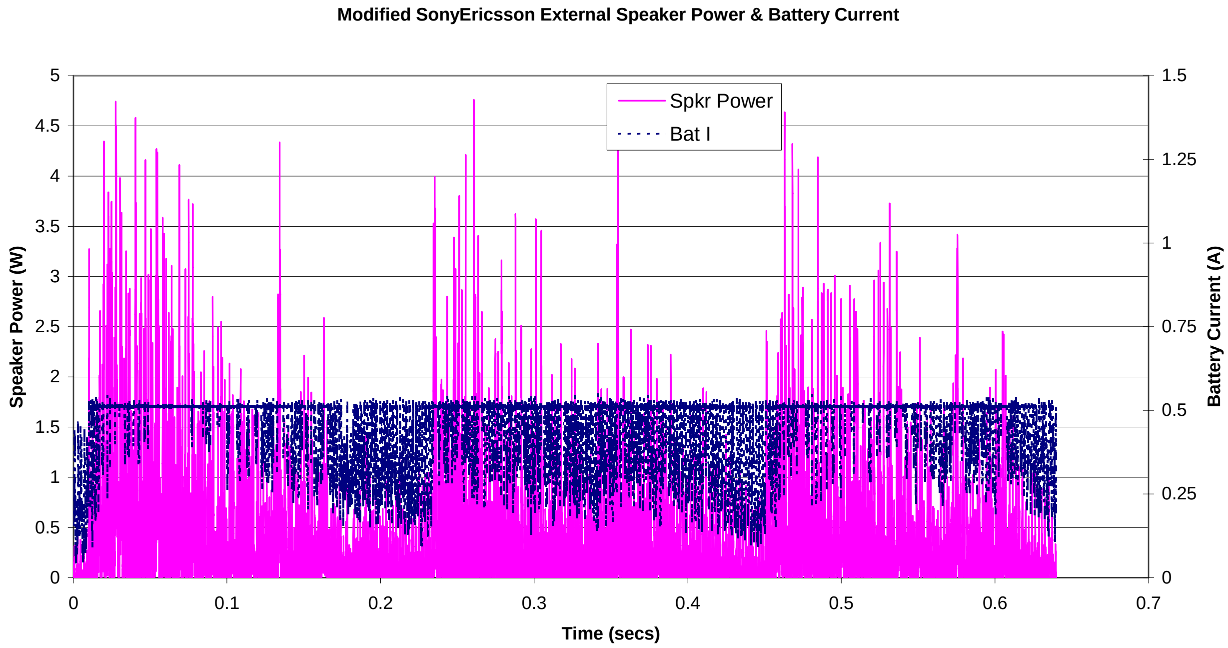

Fig 10: Battery current and speaker power while playing music, modified setup driving 4 x 8Ω speakers with audio amp powered from a supercapacitor at 5V.

Table 2 below compares 1) speaker power and 2) battery current between the 2 cases.

Adding the supercapacitor, even though the battery current is limited to approximately the same value as the standard case,

- Approximately doubles peak speaker power, and
- Increases RMS speaker power by 67%.

This makes the music sound much fuller and richer. Further, the supercapacitor enables the battery to service other peak loads in the phone, such as an RF transmit pulse in response to a network poll without affecting the quality of the music.

Table 2

	Standard mobile phone setup without supercapacitor	Mobile phone setup with Supercapacitor
Peak Battery Current	0.56A	0.54A
Average Battery Current	0.172A	0.443A
Peak Speaker Power	**2.24W**	**4.96W**
Average Speaker Power	0.207W	0.335W
Crest Factor	10.82	14.83
RMS Speaker Power	0.36W	0.6W

Conclusions
CAP-XX used three cases to compare audio quality and power, testing typical mobile-phone audio circuits both with and without a supercapacitor:

1. A 100Hz bass beat
2. A pure tone while responding to a network poll
3. A piece of music

In all three cases, the supercapacitor a) increased speaker power by 2 to 3 times for no increase in peak battery current, b) lifted the audio amp power supply from ~3.6V (Vbattery) to 5V, c) stiffened the 5V rail so there was no droop during other peak loads a phone must supply, and d) halved the speaker impedance from 8Ω to 4Ω.

In the individual test cases, the supercapacitor:

1. Tripled peak speaker power from 1.65W to 5.2W, demonstrating a fuller bass sound during the 100Hz bass-beat test.
2. Provided a stiff voltage rail to eliminate distortion while simultaneously transmitting data and responding to a network poll during the 1KHz-tone test.
3. More than doubled peak speaker power from 2.24W to 4.96W while maintaining peak battery current at ~0.5A while CAP-XX played a piece of music to compare an unmodified MPS60 to a supercapacitor-powered amplifier and speakers.

The supercapacitor's high energy storage combined with low ESR enables it to supply an audio amplifier at 5V and supply peak currents of over 1A with little noise on the 5V rail, while drawing only average current of a few 100mA from the battery.

In summary, a supercapacitor in a mobile phone can provide a far richer music experience by:

1. More than doubling speaker power so music sounds much fuller and richer, and
2. Offloading peak power demands from an overtaxed battery to eliminate the buzzing and distortion that's common when simultaneously transmitting wireless data and playing music.

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