Don Lancaster's

Tech Musings

AC power measurement
Low cost Adobe Acrobat
Rapid simultaneous A/D
Solid state power meters
Home energy monitoring

April, 1998

Accurate measurrment of real world ac power has long been the bane of beginning EE students. Especially ac power in the presence of phase shifts, harmonics, and nonlinear loads.

Power measurement difficulties also partly explain why "magic lamp" and other misinformed "free energy" pseudoscience scams still persist on the web. And why you probably have not yet done your own careful home power inventory to try and trim your personal power bill.

Thankfully, there's now bunches of new ways to accurately view and measure ac power. But before we look at these new happenings, let's once again go over some…

AC Power Fundamentals

Work gets done any time you have any force actually move something through a distance. *Energy* is defined as the capacity for doing work. And *power* is the *time rate* of doing work. Electrical power is often measured in *Watts* or *Kilowatts*. Electrical energy is sold by the *Kilowatt Hour*.

Say you have a black box with two access terminals on it. Measure the *instantaneous* voltage across these terminals. Measure the instantaneous current that is going into one of the terminals. The *instantaneous* product of the voltage in volts and the current in amps should be your instantaneous power in watts.

If the current and voltage are both positive or are both negative, your instantaneous power is going *into* the black box. We say the black box acts as a *load* or a *sink* that is consuming power. Presumably, the input power is internally developing heat; moving something where it does not want to go; emitting light; altering chemical states; building up some electric or magnetic field; or otherwise doing some sort of work.

One watt of power over one hour equals one *watt hour* of energy. A thousand watts for one hour (or one watt for a thousand hours) gives you one *kilowatt hour* of energy.

For which you usually pay your power company a dime.

On the other hand, if the terminal voltage is positive and your current is negative or vice versa, we'll say the black box is a *generator* or a *source* which is now *producing* power. The generated power has to come from some other external energy source; by diminishing the strength of any previously built up internal electrical or magnetic fields; through chemical conversion to lower energy states; or by some other means that strictly and absolutely conserves total energy.

Minus, of course, the irreversible fraction *always* lost as unrecoverable low grade heat. Carnot *always* gets his cut. Mordita and Bakeesh.

The tricky thing about ac "loads" is that they sometimes are a source of energy and sometimes are a sink of energy. Thus, power flow in typical real world ac devices can be a two way street. In and out.

Let's use figure one to see some of the problems that power waveforms can cause for us.

In figure 1A, we have an ac source driving a linear resistive load. A hot

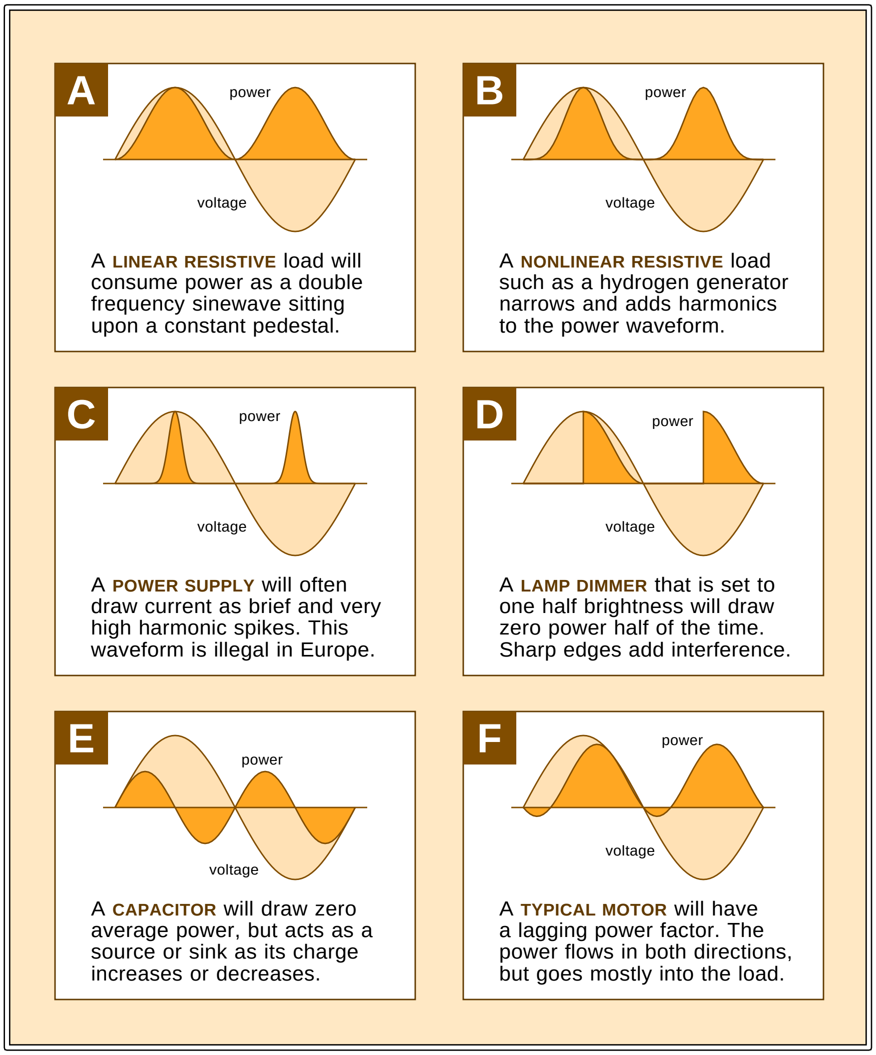

Fig. 1 – TYPICAL AC POWER WAVEFORMS have long been very difficult to accurately display and measure. Owing to their unusual shapes.

TO MEASURE POWER:

1. Low pass prefilter voltage and current waveforms so they do not change much in an 80 microsecond interval. Do this identically and sharply.
2. Starting with a zero crossing and a minimum of exactly 12,000 line locked times per second, accurately sample and record the voltage.
3. Accurately sample and record the current at precisely the same time the voltage is sampled.
4. Accurately multiply the sampled current times the sampled voltage. Sum these results. Make sure the multiplication accuracy and precision is consistent with the expected crest factors involved.
5. Repeat the measurement, multiplication, and summing exactly 12,000 times. Then divide the summed result by 12,000 to find the ac power consumed or delivered during that one second interval. The result will be both the power in watts and the consumed energy in watt seconds.
6. Multiply the watt seconds by 3600 to get the actual average energy consumption in kilowatt hours.

TO CALCULATE ELECTRICAL COSTS:

7. Add up the expected actual use hours per month, taking into account the on-off duty cycle and the exact number of days in the target month. Then multiply this times the kilowatt hours to get the kilowatt hours actually consumed for the chosen month.
8. Multiply the kilowatt hours used per month by the cost per kilowatt hour to find your monthly operating cost. Sum the monthly operating costs to get the yearly operating cost of the electricity used.

Fig. 2 – ONE USEFUL METHOD to accurately measure ac power.

water heater, maybe. Input voltage (shown) and current (not shown) will both be sinewaves, and they will both be in phase with each other. Your power waveform should always be positive and should vary at twice the frequency of the input voltage.

In figure 1B, we drive a nonlinear resistive load. A hydrogen generator perhaps. Or something else which might draw disproportionately more current at high input voltages. The current waveform will now involve *harmonics*. The power waveform is still always positive, and still varies at twice the input frequency. Only this time, the power waveshape peaks are a lot narrower.

In figure 1C, we show the power waveform typical of a capacitor input full wave rectifier. Such a *nonlinear switched load* is common in many electronic power supplies. Power is only briefly drawn near the middle of each ac half cycle when the diodes conduct. In this case, the current and voltage are still technically in phase, but the current waveform has very strong and objectionable harmonics.

In figure 1D, you should find the waveform typical of a lamp dimmer set to half brightness. No power at all gets drawn for the first quarter cycle till the lamp is turned on by a triac or a silicon controlled rectifier. Such a waveform clearly is phase shifted and has strong harmonics. In addition, the sharp leading edge is a possible EMI source of radio interference.

In figure 1E, we input to a pure capacitor. Your voltage and current waveforms will get phase shifted by precisely 90 degrees, with the current leading. There are times when your capacitor is accepting current and increasing its internal electric field storage. There are times when the capacitor is *producing* current when decreasing its internal storage. *The average long term power is zero!*.

Driving any pure inductor would again have your voltage and current waveforms shifted by precisely 90 degrees. Only this time, the voltage is leading. Good old ELI the ICE man. Once again, your current goes both ways, and the long term power always averages to zero.

In figure 1F, we view the super important case of a typical motor. Here we have a lagging load that is mostly resistive, combined with the inductance of the motor winding. A *power factor* can be defined as the cosine of the phase angle. A common power factor of 0.8 implies a phase shift around 37 degrees. With such a lagging load, the current still goes both ways. Except the dominant flow this time is into the motor. Note the two brief and rather low power reversals in each line cycle.

I have purposely left the current waveforms out of this figure to keep things simple. I invite you to sketch all these in as an "excercise for the serious student". For there's lots to be learned here.

Summing up: In pretty near any reasonable ac device you can think of, the power waveform will be more or less nonlinear. Typically, you'll have a hard-to-measure average long term value overlain by some cyclic double frequency waveform. Thus, accurate ac power measurement all comes down to measurement of an arbitrary waveform that is formed by the product of two values. And these days, the best way to make any low frequency measurement is to…

Do It Digitally

Figure two shows you a good way to accurately calculate ac power. While you could dream up an analog multiplier circuit, such devices will quickly get into several *crest factor* problems. The crest factor is the ratio of your peak power to the average power. Analog solutions tend to get complex if the needed crest factor exceeds three or so.

Dimmers (figure 1D) and rectifiers (figure 1C) often exceed this value.

Instead, the trick is to A/D convert your current and voltage waveforms, sampling them digitally *at the same time*, and then digitally multiply them together. How many samples? I'd vote for at least 100 per half cycle, or 12,000 per second. This sounds high at first glance, but with the often seen diode waveforms of figure 1C, this would only leave you with ten or so non-zero samples per half cycle. And an accuracy at best of five percent.

Note that any power measurement scheme either has to measure one full

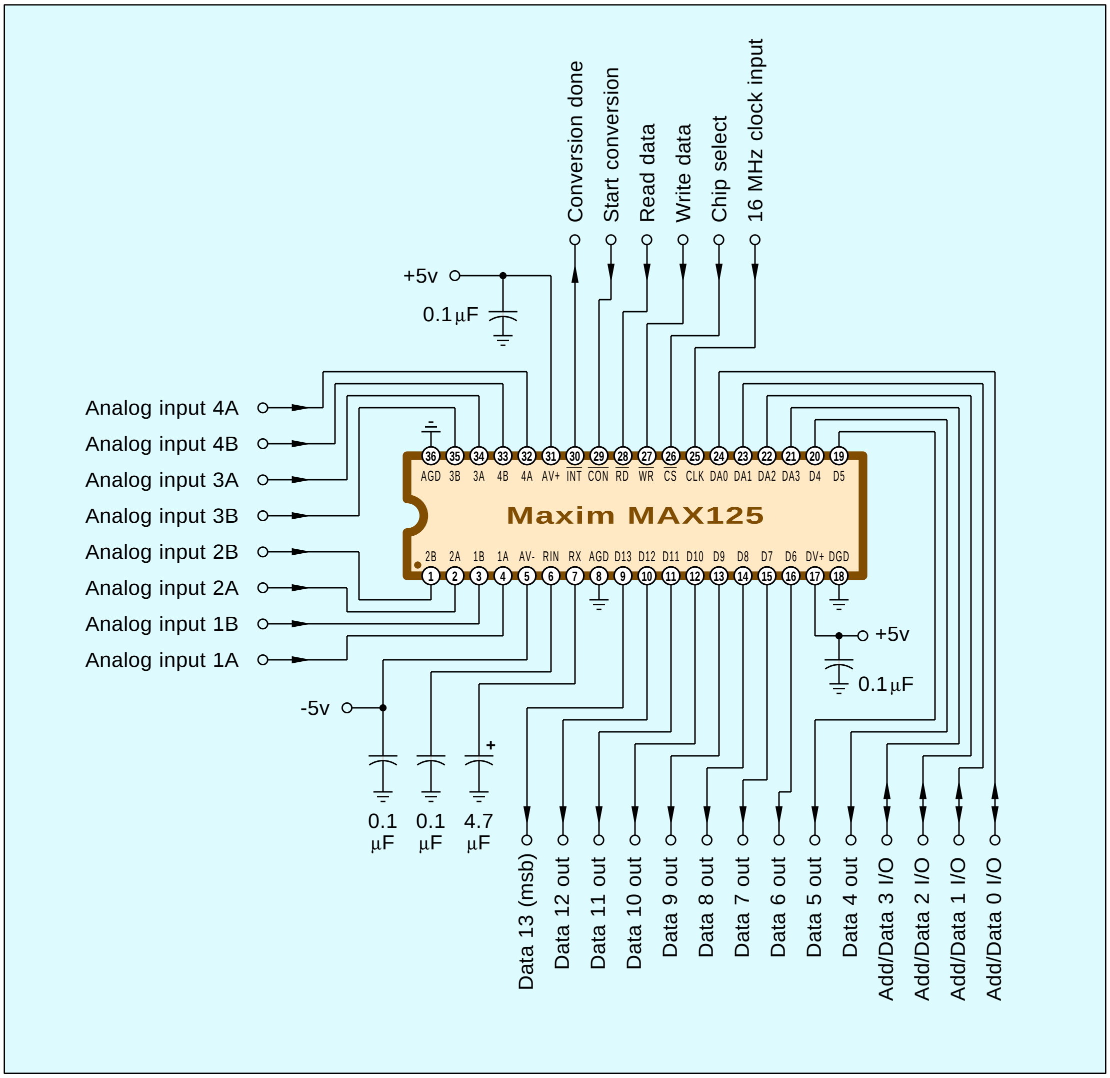

Fig. 3 – THE NEW MAXIM MAX125 lets you simultaneously sample voltage and current. This is a crucial first step in digital power measurement. A microcontroller does the actual multiplication.

cycle or else has to measure a "large number" of cycles. Otherwise errors are certain to happen when portions of cycles are unfairly or randomly represented. It does pay to lock your measurement scheme to the voltage or current zero crossings such that whole cycles are always measured.

Strong lowpass filtering of both voltage and current waveforms is a good idea to reduce high frequency noise. But it is super important that *identical* filters get applied to both voltage and current to prevent group delay problems.

The voltage and the current really should get measured at *exactly* the same time. But if your sample rate is high enough, you might get by taking the average of two sequential current measurements. Fer instance…

#46 - current
#47 - voltage
#48 - current
#49 - voltage
#50 - current

…and then multiply #47 voltage times the *average* of current #46 and current #48. Similarly, multiply #49 voltage times the average of current #48 and current #50, and so on.

A PIC is your obvious choice for lowest cost ac power measurement calculations. Suitable current sensors might include a current transformer (*Amecon* is one better source), Hall effect sensors, clamp around probes, or measuring the voltage drop across a suitable small series resistor.

The New Stuff

As we already found out back in MUSE112.PDF, those ordinary cheap voltmeters and ammeters are totally useless to measure real ac power. Such meters measure average rather than true rms. They all lie like a rug, because their "answer" is so highly waveshape dependent.

Here are several of the latest new developments in low cost accurate ac power measurement…

True rms meters– The costs for digital or analog meters with a true rms ability is dropping dramatically. Even *Radio Shack* now resells \$79 digital voltmeters that can provide true rms. A true rms meter gives you

A FEW AC POWER MEASUREMENT RESOURCES

Amecon 1900 Chris Ln Anaheim CA 92805 (714) 634-2220	**EPRI Journal** PO Box 10412 Palo Alto CA 94303 (415) 855-2000	**Home Automator** 2258 Sandy Lane Mebane NC 27302 (910) 578-9519	**Remote Measurement** 2633 Eastlake Ave #200 Seattle WA 98102 (206) 328-2255
Circuit Cellar Ink 4 Park St #20 Vernon CT 06066 (203) 875-2751	**Electronics Now** 500-B Bi-County Blvd Farmingdale NY 11735 (516) 293-3000	**Home Power** PO Box 520 Ashland OR 97520 (800) 707-6585	**Rocky Mountain Institute** 1739 Snowmass Creek Rd Snowmass CO 81654 (970) 927-3851
Digitest Services 4518 Chateau Dr Albany GA 31707 (912) 883-4047	**Energy Depot** 1797 Northeast Exy #100 Atlanta GA 30329 (404) 633-9099	**Maxim** 120 San Gabriel Dr Sunnyvale CA 94086 (800) 998-8800	**Zomeworks** PO Box 25805 Albuquerque NM 87125 (505) 242-5354

total waveform and full harmonic independence. So long as you stay under acceptable crest factors. Which at least gets rid of the really stupid measurement mistakes. But note that you still cannot multiply rms volts times rms amps to get power, since you don't know the phase angle.

Digital storage scopes– The latest of DSO's and many computer data acquisition plug ins now permit you to multiply input values together and display your results. Which lets you directly view those power waveforms of figure one. Something that once was horrendously difficult to do.

Analog Devices AD7750– This new chip family was originally intended as a $2.50 solid state replacement for a European 50 Hertz power meter. Inside you will find a pair of high accuracy A/D converters, a digital multiplier, a digital-to-frequency converter, and even stepper motor drivers for a mechanical totalizer.

Some external filter parts seem to be required for 60 Hertz operation. The output frequencies of only a few Hertz are surprisingly low, so they seem best at averages rather than for cycle-by-cycle measurements.

Their data sheet does mention crest factors of two. Which suggests that it may not do all that great on stranger waveforms. The European method around high crest factors is to simply make them illegal. Which is what IEC standard 555-2 is all about. And why there is so much excitment over those new power factor correction chips and circuits.

Analog Devices website is found at *www.analog.com*.

Maxim MAX125– This is a brand new *simultaneous* multi-channel A/D converter. It is specifically designed for power meters, motor controls, and for power factor monitoring. There are eight analog inputs which can be routed to a 4PDT selector switch and then input to four simultaneous A/D converters. Fourteen bit conversion is provided in three microseconds, by using the circuit of figure three.

An external clock is needed. Its typical value is 16 MHz.

There are fourteen parallel data outputs, the lower four of which are used as bidirectional address inputs to program one of eight conversions plus a power down. The choices are A or B sides of one through four channels of conversion. It takes three microseconds to do the one-channel conversion and twelve microseconds for a four-channel conversion.

There are four control inputs of chip select, read enable, write enable, and conversion start. There's also a "conversion done" output normally used as an interrupt.

After conversion is done, the first read enable reads out channel 1 as parallel data. The next one outputs channel 2. Up to the fourth one that reads channel 4.

For single phase power use, you normally only select a single side of channel one for current and two for voltage. The full four channels may be required for three phase power systems or exotic motor controls.

Note that this chip only measures your input values for you, doing so accurately and simultaneously. Your host PIC or whatever has to do the actual multiplies for calculation of the instantaneous power.

The interface to a PIC or other microcontroller is fairly simple. An external data latch may be needed in some systems. Evalutaion kits and free chip samples are available.

Maxim's website can be found at *www.maxim-ic.com*.

NEED HELP?

Phone or write all your US Tech Musings questions to:

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US email: *don@tinaja.com*
Web page: *www.tinaja.com*

Digitest DT500– This is a unique home power monitor that I've been testing. In a $399 list package about the size of a box of cereal, you can monitor 120/240 volt ac appliances for your voltage, current, kilowatt hours, and duty cycle. And power costs in dollars and cents.

You can plug an appliance or other load into the back of the unit, use an accessory snap-around current probe, or else directly input a custom test voltage that is related to current. You can very quickly find out that your refrigerator is costing you $19.37 per month to use.

Around 3600 current and voltage samples per second are taken in this Intel 8751 based device. This pretty much follows most of figure two.

NAMES AND NUMBERS

Adobe Acrobat
1585 Charleston Rd
Mountain View CA 94039
(800) 833-6687

Card Technology
300 S Wacker Dr 18th fl
Chicago IL 60606
(312) 913-1334

Data Storage
10 Tara Blvd 5th fl
Nashua NH 03062
(603) 891-0123

Forming & Fabricating
One SME Dr
Dearborn MI 48128
(313) 271-1500

Klockit
PO Box 636
Lake Geneva WI 53147
(800) 556-2548

Lindsay Publications
PO Box 538
Bradley IL 60915
(815) 935-5353

Logic Devices
1320 Ocean Dr
Sunnyvale CA 94089
(408) 542-5400

Mabry Publishing
PO Box 31926
Seattle WA 98103
(206) 634-1443

Magnet Applications
415 Sargon Way Ste G
Hrosham PA 19044
(800) 437-8890

muRata-Erie
2200 Lake Park Dr
Smyrna GA 30080
(800) 731-9172

Precision Navigation
1235 Pear Ave #111
Mountain View CA 94043
(415) 962-8777

Roberts Electric
311 N Morgan St
Chicago IL 60607
(312) 829-1365

Science/AAAS
1333 H St NW
Washington DC 20005
(202) 326-6400

Surplus Direct
Box 2000
Hood River OR 97031
(800) 753-7877

Synergetics
Box 809
Thatcher AZ 85552
(520) 428-4073

Don Thompson Seminars
20650 Prairie St
Chatsworth CA 91311
(800) 423-5400 X2537

The DT500 certainly does what it claims to, and sure is a lot of fun to play with. Especially for doing your own home energy inventory. On the other hand, the ergonometrics aren't all that great, the LCD desperately needs backlit, the cents per KWH cost entry is klutzy, and there's zero I/O provision for data capture, record keeping, or for any history plotting. In addition, some sort of a wireless current sensor with a 35 foot range sure would be handy.

The Remote Measurement Systems Power Sentry– This is a neat little infrared sensor that sticks to the glass of an ordinary power meter and then counts every time the black mark on the disk comes around. Yes, the $79 device is not only allowed by certain power companies, but it is actually approved of and strongly encouraged. A companion ADC-1 interface and control software for Mac or PC lets you plot a month's power use in half second intervals.

I'm trying to get one of these for further test and evaluation. I'm on good enough terms with our town's power company that approval should not be much of a hassle. Once again, a wireless unit with a 35 foot range sure would be a lot more convenient.

Remote Measurement's website is *www.measure.com*

I've gathered a few preliminary sources for ac power measurement and home energy management as this month's resource sidebar. I'll try to work up a more extensive survey for a future column. More on rms power measurement in MUSE112.PDF on my *www.tinaja.com*.

New Tech Lit

From *Logic Devices*, a new *Power of Signal Processing* data book. You will find special video filter, alpha mixer channel, and histogram chips here. From *MuRata*, a new *RF and Microwave Products Catalog*. You'll find bunches of ceramic resonator and surface acoustic wave (SAW) devices in this manual.

From *Texas Instruments*, a pair of new CD ROM data books: Titled *InfoNavigator* and the *Future of DSP Technology*. Also through T.I., data sheets on their new low cost TSL253 light-to-voltage converter.

Use of DNA computing to solve a major math problem appears on pages 446-449 of *Science* for October 17, 1997. Volume 278.

A booket on higher performance permanent magnets is available from *Magnet Applications*. Some low cost hygrometers are retailed by *Klockit*. Hydraulic bargains can be found at *Roberts*. Superb laser printer service seminars, and printer maint manuals are offered by *Don Thompson*.

Richard Grier has got a new *Visual Basic Programmer's Guide to Serial Communications*, his useful text on low level Windows comm access. Published by *Mabry*. From *Lindsay Publications*, two volumes of their "new-old" 1906 reprint series titled *Experimental Science; Elementary Practical and Experimental Physics.*

Featured trade journals for this month are *Data Storage* for hard disk insiders, *Forming & Fabricating* for sheet metal, and *Card Technology* on smart cards.

The latest and finest version of *Adobe Acrobat* is newly available for $49 through the *Academic Software* division of *Surplus Direct*. Acrobat includes the powerful Distiller 3.01 program which makes an outstanding host based PostScript-as-language computer. More details on the power of raw PostScript computing can be found in DISTLANG.HTML and also in POSTFLUT.PDF on my *Guru's Lair* at *www.tinaja.com*.

For nearly all individuals and all small scale startups most of the time, an involvement with patents is likely to end up as a net total loss of time, energy, money, and sanity. Find out why in my *The Case Against Patents* package. Included are my tested and proven real-world alternatives. Per my nearby *Synergetics* ad.

Plus the usual reminder about my *Guru's Lair* website you will find at *www.tinaja.com*. Some of the latest additions include new info on virtual reality, surplus & auction details, and newly expanded Bezier cubic spline coverage. I've also got my brand new *InfoPack* consulting services and my telephone module bargains here.

Check these out.

As usual, most of the mentioned items should appear in our *Names & Numbers* or *AC Power Management* sidebars. Always be sure to check here first before calling our US tech helpline. Let's hear from you. ✦