Perfect Solution of Piezoelectric Component Measurement

I. Forward

Ultrasonic piezoelectricity component used to be concretely analyzed through two methods:

a. Impedance analyzer (such as Agilent 4294A), with the advantages of being automatic, fast, accurate, and the disadvantages of being rather expensive with the cost of several hundred thousand.

b. Signal generator, frequency meter, millivoltmeter, etc. combined by several instruments, with the advantage of low price, and the disadvantages of being difficult to operate, low accuracy, no phase information, single measurement parameter, and long measurement time.

Tonghui offers nice solutions of low-frequency ultrasonic piezoelectricity component with analogous performance of impedance analyzer at a low cost (only around 20,000 to 60,000 RMB).

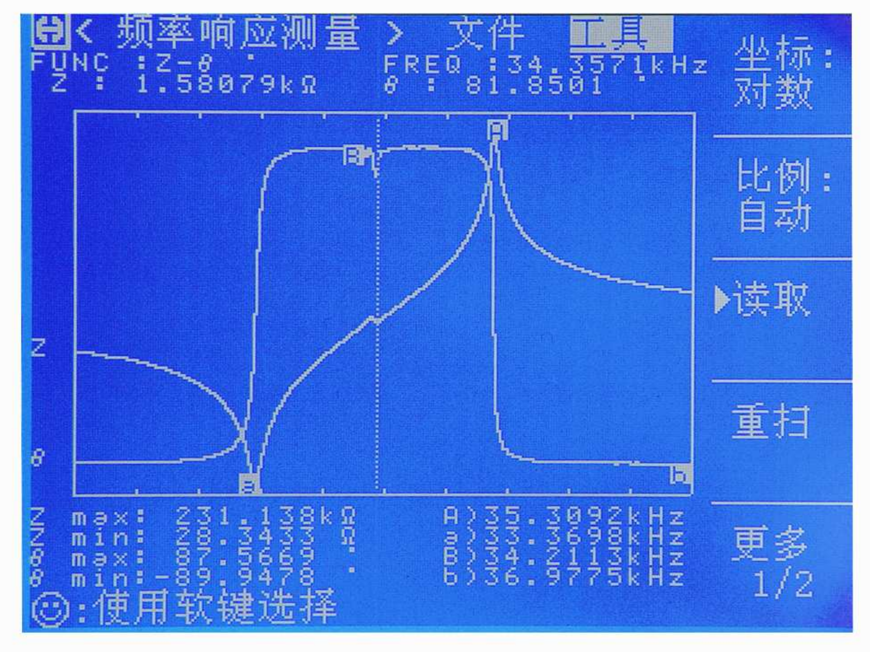
II. Introduction of Frequency Response Analysis Function of Tonghui Automatic Component Analyzer

TH2818/TH2828S automatic component analyzer, low-frequency impedance meter with high precision, wide measurement range and 6-digit resolution, has sound component frequency response analysis function.

The instruments' measurement frequency ranges respectively are:

TH2818: 20Hz-300kHz, 10mHz resolution, Jiangsu New & Hi-tech Product.

TH2828S: 20Hz-1MHz, 1mHz resolution, Jiangsu Key Scientific and Technological Project



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Z  max:  231.138kΩ       A)35.3092kHz
Z  min:  28.3433  Ω      a)33.3698kHz
θ  max:  87.5669         B)34.2113kHz
θ  min:-89.9478          b)36.9775kHz
☺:使用软键选择
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TH2818/TH2828S's frequency response analysis measurement function is applicable to analyze impedance of ultrasonic component with frequency from 100kHz to 1MHz. In the pre-set frequency range (20Hz to 300kHz or 20Hz to 1MHz), please perform automatic scanning measurement for the component under test in linearity or logarithm mode according to scanning frequency point of 120, 240, 480 or 960 each time, and the test signal can be set according to user's requirement. Then the response waveforms of change of component's primary and secondary parameters with frequency are dynamically displayed on LCD screen.

In the response waveform, horizontal axis is frequency, and vertical axis is the selected measurement parameter.

Measurement result at any frequency point in the scan range is displayed and read out on the screen. And when component’s frequency response is displayed, the following parameters are displayed on the upside of screen:

a. Current displayed parameter combinations, such as Z/θ, Cp/D, etc;

b. Corresponding frequency at the intersecting point of vertical imaginary and response waveform;

c. Measurement value of set parameter at the corresponding frequency, such as Z, θ, etc.

By using software and direction keys, location of imaginary line can be adjusted, and measurement value of random position’s corresponding frequency can be read out.

At the same time, the following parameters of the device under test in the scan range are displayed on the downside of screen:

a. Maximum of primary parameter (such as Zmax) and corresponding frequency;

b. Minimum of primary parameter (such as Zmin) and corresponding frequency;

c. Maximum of secondary parameter (such as θmax) and corresponding frequency;

d. Minimum of secondary parameter (such as θmin) and corresponding frequency.

When user performs impedance analysis of ultrasonic component, the following common parameters of ultrasonic component are also displayed (belonging to customized special parameters):

Static capacitance (1kHz)C^T;

Min. impedance Zmin and its corresponding frequency fs (fs: serial resonance frequency);

Max. impedance Zmax and its corresponding frequency fp (fp: parallel resonance frequency);

Coupling coefficient $k_p \approx \sqrt{\frac{f_p - f_s}{f_s} \times 2.51}$;

Mechanical quality factor $Q_m \approx \frac{f_p^2}{2\pi f_s Z_{\min} C^T (f_p^2 - f_s^2)}$, etc.

Customer can ask for demanded measurement parameters according to your own need, such as free dielectric constant ε^T_{33}, and we customize to perform the measurement and mathematical operation to meet customer’s need.

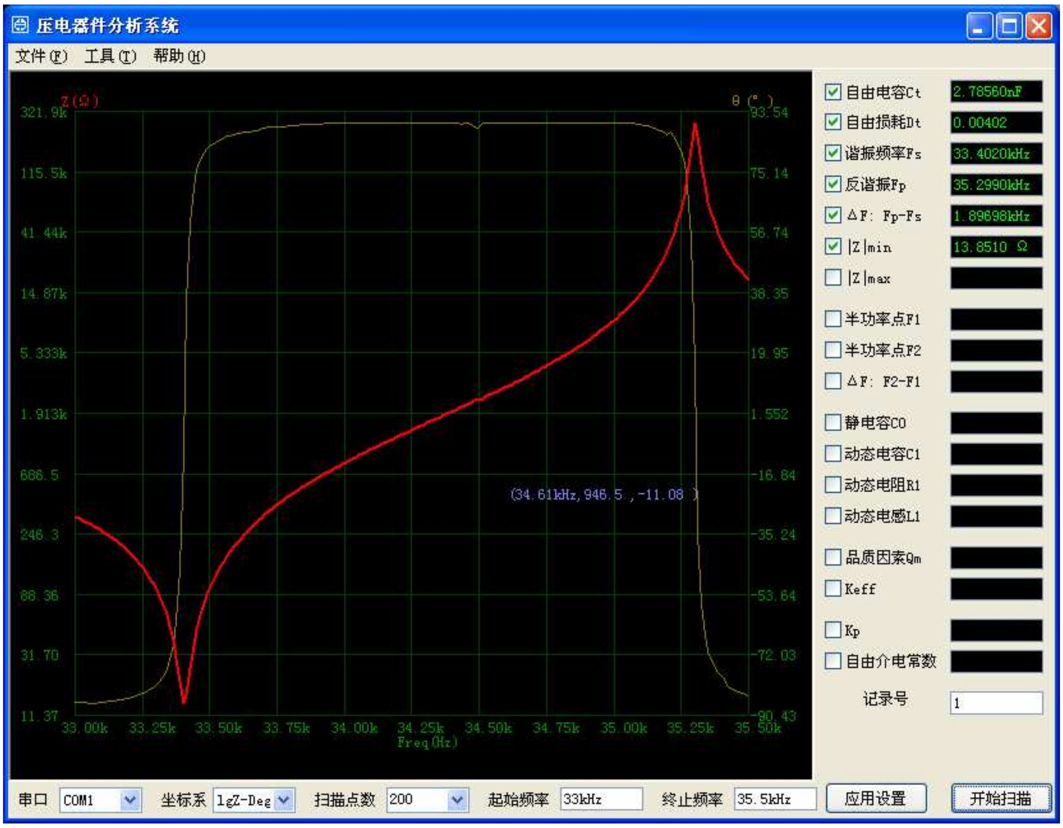
TH2818 has originally equipped RS232C interface and optional GPIB interface. And TH2828S has originally equipped RS232C and GPIB interfaces.

Through the above interfaces, the instrument is connected with master computer to communicate, and the measurement result and frequency response waveform are sent to computer, which is convenient for user to automatically make test report on computer to improve production efficiency.

User can also program on computer, control instrument’s test frequency and read measurement result through interface. Then applicable impedance analysis interface is formed.

More complicated piezoelectric component analysis function can be realized through our company’s specific software, and the software interfaces are shown as follows:

A．Impedance/phase – frequency characteristic



☑ 自由电容Ct 2.78560nF
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☑ 反谐振Fp 35.2990kHz
☑ ΔF: Fp-Fs 1.89698kHz
☑ |Z|min 13.8510 Ω
□ |Z|max
□ 半功率点F1
□ 半功率点F2
□ ΔF: F2-F1
□ 静电容C0
□ 动态电容C1
□ 动态电阻R1
□ 动态电感L1
□ 品质因素Qm
□ Keff
□ Kp
□ 自由介电常数
记录号 1

串口 COM1
坐标系 lgZ-Deg
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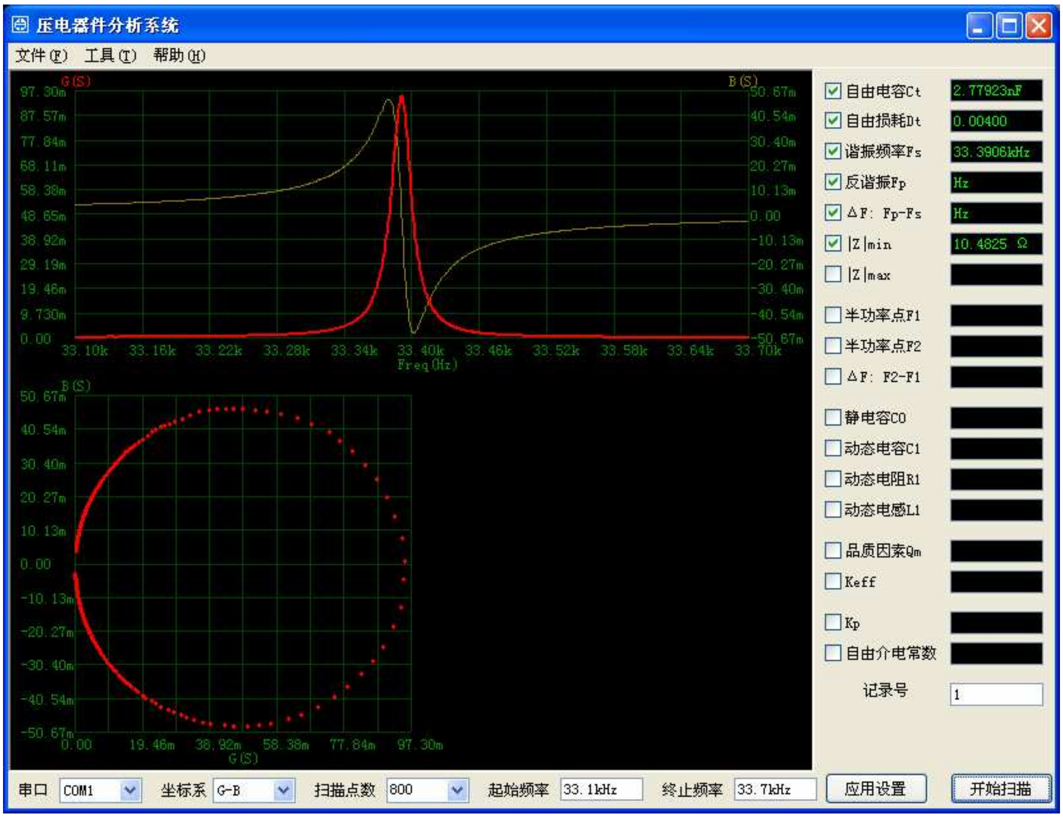
起始频率 33kHz
终止频率 35.5kHz

B． conductance/susceptance – frequency characteristic, conductance-susceptance characteristic



☑ 自由电容Ct 2.77923nF
☑ 自由损耗Dt 0.00400
☑ 谐振频率Fs 33.3906kHz
☑ 反谐振Fp Hz
☑ ΔF: Fp-Fs Hz
☑ |Z|min 10.4825 Ω
☐ |Z|max
☐ 半功率点F1
☐ 半功率点F2
☐ ΔF: F2-F1
☐ 静电容C0
☐ 动态电容C1
☐ 动态电阻R1
☐ 动态电感L1
☐ 品质因素Qm
☐ Keff
☐ Kp
☐ 自由介电常数
记录号 1

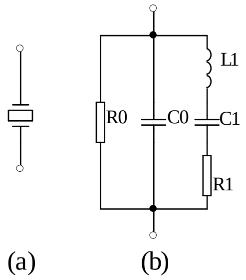
串口 COM1 坐标系 G-B 扫描点数 800 起始频率 33.1kHz 终止频率 33.7kHz

II. Characteristics of piezoelectric component and instrument’s analysis function

Performance of piezoelectric ceramic piece, piezoelectric transducer, oscillation system (transducer and booster, mould) can be judged through automatic analyzer, and the following are the most important parameters:

For piezoelectric component, its frequency characteristic changes with frequency. And it needs very complicated circuit network to completely describe a piezoelectric component. We can choose a simple network in the interested frequency range (including inductance, resistance, capacitance) to describe, and the practice proves that it can reappear needed netework characteristics better to build up the network using inductance, resistance and capacitance in the undermentioned network.

For general piezoelectric component, in the frequency area away from some resonance frequency, there’s no other resonance, so the component can be simulated by umpty inductances, resistances and capacitances in the frequency area around the resonance frequency, and its corresponding equivalent circuit is shown as:



Equivalent circuit of general piezoelectric component

Figure (a) is symbol of piezoelectric component, and figure (b) is equivalent circuit of piezoelectric component, where C0 is static capacitance, R1, C1, L1 are respectively resistance, capacitance, inductance of static impedance, R0 is insulation impedance of material.

In the above equivalent circuit, because circuit is in parallel mode, it's more convenient to apply admittance to analyze. Suppose admittance of the whole circuit to be Y, that of parallel branch (composed of R0 and C0, and called static admittance) to be Y0, that of serial branch (composed of R1, L1, C1, and called dynamic admittance) to be Y1, then

Y= Y0 + Y1 Y0 = 1/R0+1/（j2πfC0） Y1 = 1/{R1+j2πf L1+1/(j2πfC1)}.

So change of sum admittance Y and dynamic admittance Y1 with frequency f can be obtained through operation (admittance-frequency characteristic).

Y and Y1 are vectors, so they should be divided into real part (conductance G) and imaginary part (susceptance B) and be graphically shown.

Figure B in last section shows two different representations of admittance characteristic. The upside figure shows conductance/susceptance's change characteristic with frequency, where the yellow line shows B(s) –f characteristic, and the red line shows G(s) –f characteristic. And the downside figure is an admittance vector plane, where the horizontal axis shows conductance G (real part of admittance), and vertical axis shows susceptance B (imaginary part of admittance). This figure shows change characteristic of admittance with frequency.

When signal frequency changes in the range around resonance frequency (serial resonance), track of vector Y1 is a circle with the center of (1/2R1, 0) and the semi diameter of 1/2R1.

When track of vector Y1 circumvolves for a round around resonance frequency, vector Y0 changes little with frequency, which can be considered as a constant. Therefore, by making parallel movement for track circle of Y1 along vertical axis in the admittance plane, track circle of change of admittance Y with frequency can be obtained, that is admittance circle.

Pursuant to the admittance circle, equivalent circuit of piezoelectric component and some other key parameters can be got.

- F_s: mechanical resonance frequency, that is working frequency of oscillation system should be designed to be much close to expectation. For cleaning machine, resonance frequencies of vibrators should be as same as possible; and for plastic welding machine or ultrasonic process, if booster or mould isn't designed well, resonance frequency of vibrator will deviate from working point.

◆ G_{max}: conductance of serial resonance, working conductance of oscillation system, it's reciprocal of dynamic resistance R1. With the same holding condition, it's better to have larger G_{max}, Gmax＝1／R1. Generally speaking, for cleaning or welding vibrator, it's around between 50ms and 500ms. If it's too small, there will be problem with working of vibrator or oscillation system. If the circuit doesn't match or transition efficiency is low, vibrator will have short life.

◆ C0: capacitance of static branch of piezoelectric component's equivalent circuit, C0＝CT－C1 (CT is free capacitance at 1kHz, C1 is capacitance of dynamic branch of the equivalent circuit). It needs to balance C0 with inductance when it's used. In circuit design of cleaning machine or ultrasonic process machine, there are two methods of using inductance balance: parallel tune and serial tune.

◆ Q_m: mechanical quality factor, $Q_m = F_s / (F2 - F1)$, larger Q_m is, higher frequency of vibrator is, so it's better to have larger Q_m, but Q_m must match with power supply, because sometimes Q_m is too high to have a matching power supply.

For cleaning vibrator, it's also better to have larger Q_m. Generally speaking, Q_m of cleaning vibrator should reach over 500. If it's too small, efficiency of vibrator will be low.

For ultrasonic process, Q_m of vibrator is around 500, and it will reach around 1000 with booster, and 1500 to 3000 with booster and mould. If it's too small, efficiency of vibrator will be low. But it can't be too large, because in that case, working bandwidth will be narrow, the power supply will be difficult to match with, power supply can't work at resonance frequency point, and equipment can't work.

◆ F2, F1: frequencies of vibrator's half power points. For the whole oscillation system of ultrasonic process (including booster and mould), the difference between F2 and F1 should be larger than 10Hz; otherwise, power supply can't work at resonance frequency point and equipment can't work because of narrow bandwidth.

Qm is directly related to difference of F2 and F1, $Q_m = Fs / (F2 - F1)$.

◆ F_p: anti-resonance frequency (mainly brought out by C0, L1), resonance frequency of parallel branch of piezoelectric vibrator. And at the frequency, the impedance of piezoelectric vibrator is the largest, and admittance smallest.

◆ Z_{max}: anti-resonance impedance. Generally, anti-resonance impedance of a transducer is more than decades thousandΩ. If anti-resonance impedance is small, usually the vibrator has short life.

◆ CT: free capacitance, capacitance of piezoelectric component at frequency of 1kHz, which is same with measured value of digital capacitance meter. This value minus dynamic capacitance C1 equals real static capacitance C0. C0 needs balance of external inductance, and C1 participates in energy transition when system works without the need of balance.

◆ dynamic resistance R1: resistance of serial branch of piezoelectric vibrator in the figure. R1＝1／D, where D is diameter of the admittance circle.

◆ dynamic inductance L1: inductance of serial branch of piezoelectric vibrator in the figure.

$L1 = \frac{R1}{2\pi(F2 - F1)}$, where R1 is dynamic resistance, F1, F2 are half power points.

◆ dynamic capacitance C1: capacitance of serial branch of piezoelectric vibrator in the figure.

$C1 = \frac{1}{4\pi^2 Fs^2 L1}$, where Fs is resonance frequency, L1 is dynamic inductance.

◆ static capacitance C0: C0＝CT－C1, where CT is free capacitance, C1 is dynamic capacitance.

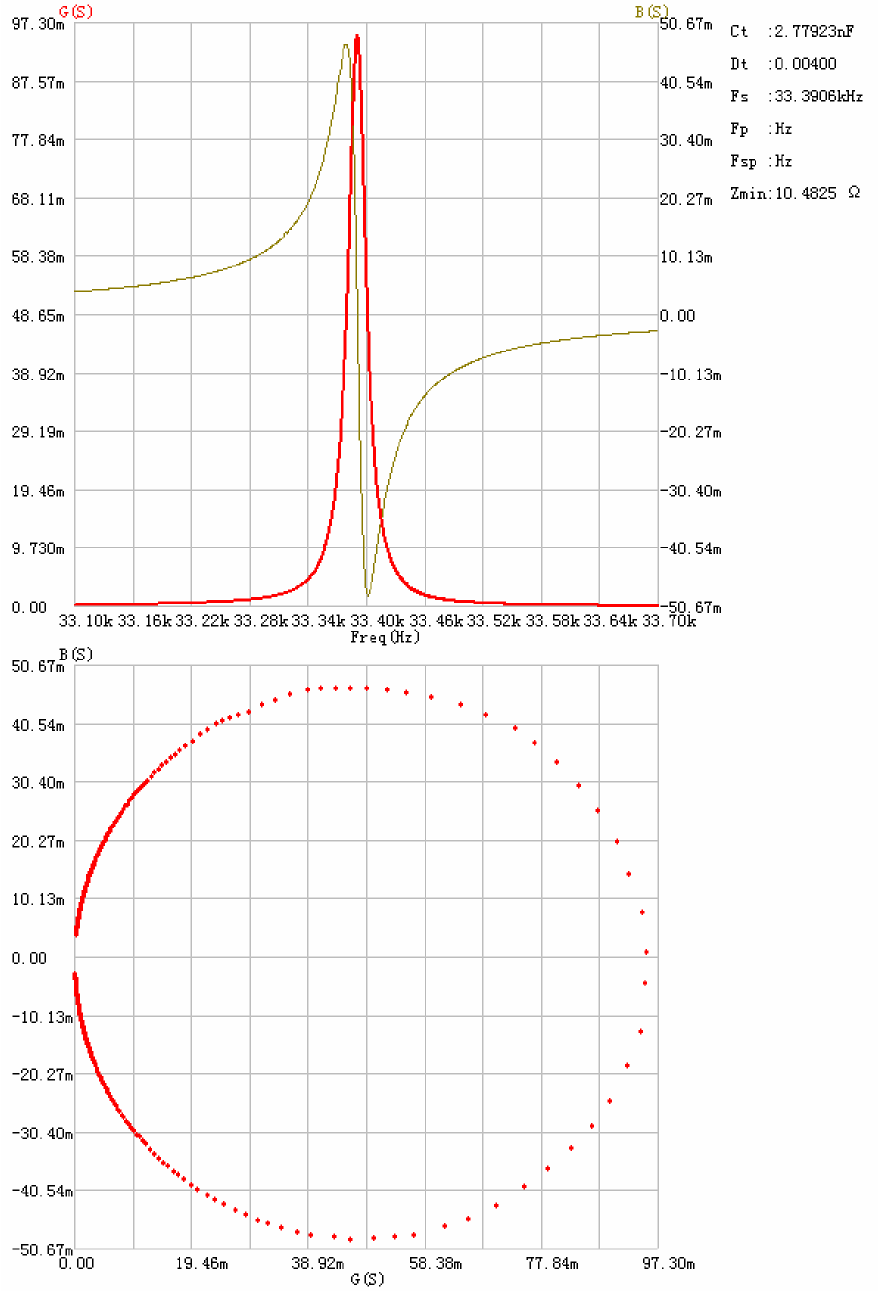
◆ K_{eff}: effective mechanical and electrical coupling coefficient. Generally speaking, larger K_{eff}, means higher conversion efficiency.

Our company's automatic component analyzer and its software are welcomed by piezoelectric component manufacturer and research institutes, and our products save capital a lot, improve efficiency, and guarantee measurement accuracy.

Tonghui not only provides piezoelectric measurement instrument with excellent performance, but also customize products to meet different requirements.

So far, this product has been used by many famous enterprises and research institutes, such as Hangzhou 715 Research Institure, Suzhou Hanning, Shantou Xianning, Shanghai Acoustic Research Institure, Wuxi Haiying Group, etc.

Here is a saved example of using Tonghui specific communication software to test piezoelectric component:



Ct :2.77923nF
Dt :0.00400
Fs :33.3906kHz
Fp :Hz
Fsp :Hz
Zmin:10.4825 Ω

Changzhou Tonghui Electronics Co., Ltd.

Add: No. 3 Tianshan Rd., New & Hi-tech District, Changzhou City, Jiangsu Province, P.R.China
Tel: 00-86-519-5132222, 5115008, 5109671, 5113342, 5109592
Fax: 00-86-519-5109972, 5195190
Post code: 213022
Website: www.tonghui.com.cn
E-mail: Sales Department sales@tonghui.com.cn
R&D Department gzq@tonghui.com.cn