IQ data in Signal analyzer MSA500 series

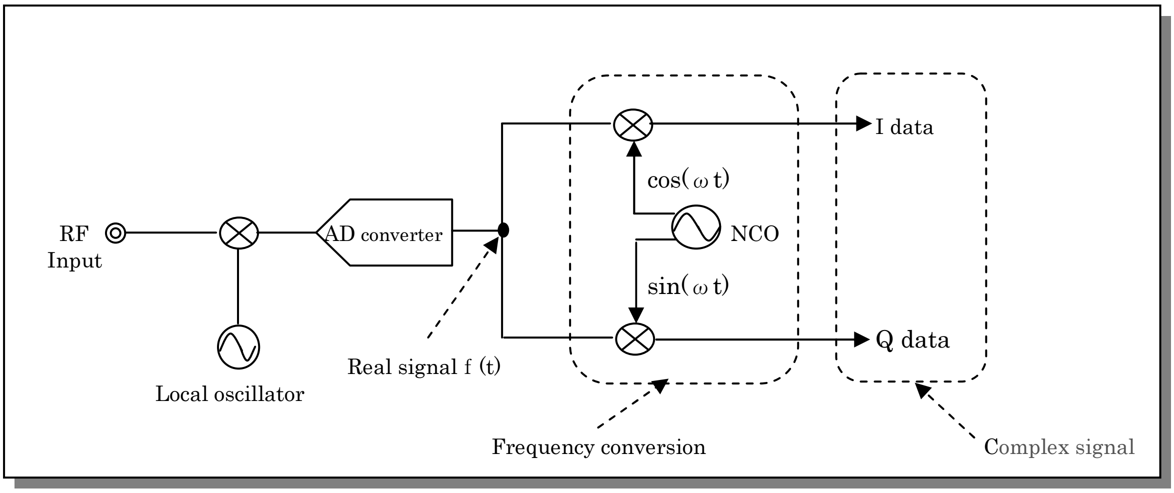
Technical report

2014.10.24

MICRONIX Corp.

At Signal analyzer (Real time spectrum analyzer) MSA500 series, after the input signal is converted into IQ signals, the digital signal processing is performed and the result is displayed on the screen.

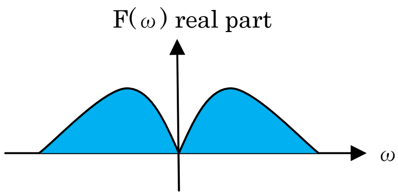
In this paper, the IQ data will be explained.

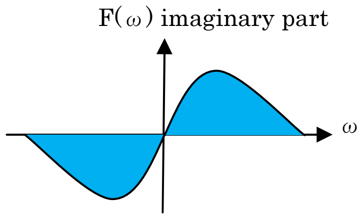


NCO : Numerical Controlled Oscillator. The cos(ωt) and sin(ωt) are output from ROM data or by being calculated by software.

The digital signal f (t) converted by ADC is a real signal.

This real signal f (t) is Fourier-transformed. ⇨ Frequency spectrum F (ω) is symmetric with respect to ω axis.





That is, the symmetry means that one side of the spectrum contains all the information of the signal f (t).

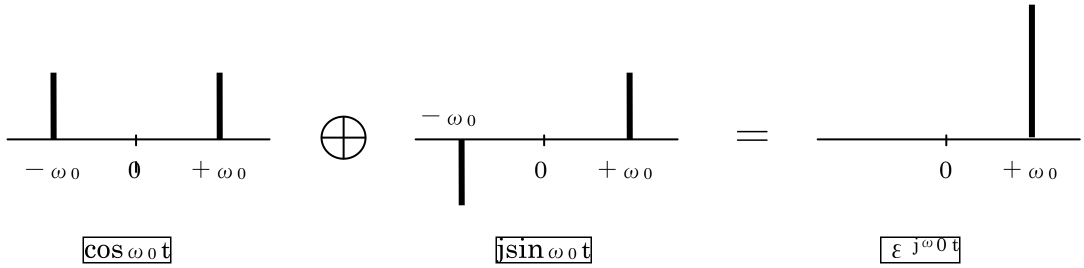
In other words, just half the information will be obtained if f (t) is a real signal.

⇩

Therefore, Fourier transform processes complex signal in which each of positive and negative output is valid data.

Frequency conversion and generation of complex signal

As a simple example of real signal, "$f(t) = \cos\omega_0 t$" is considered.

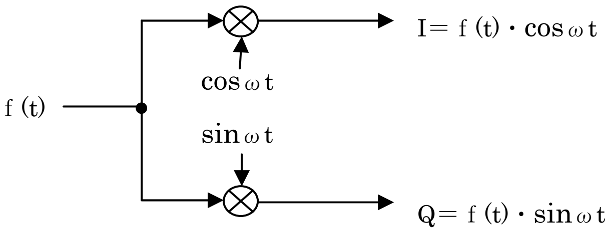


The analysis signal taking out only the positive frequency components is a complex number in which the real part is original "cos" and the imaginary part is "sin".

⇩

The analysis signal is a complex signal or orthogonal signal.

The figure below shows a circuit in which the real signal f (t) is converted into a complex signal at the same time as frequency conversion.



Normally, in case of multiplication of two complex signals ;

$(a+jb) \cdot (c+jd) = (ac-bd) + j(ad+bc)$

As shown in the above equation, four multipliers of ac, bd, ad and bc are needed. However, because b is 0 if the input is a real signal, the multipliers are reduced to two of ac and ad. This is shown in above figure.

Meantime, $a = f(t)$、$c = \cos\omega t$、$d = \sin\omega t$.

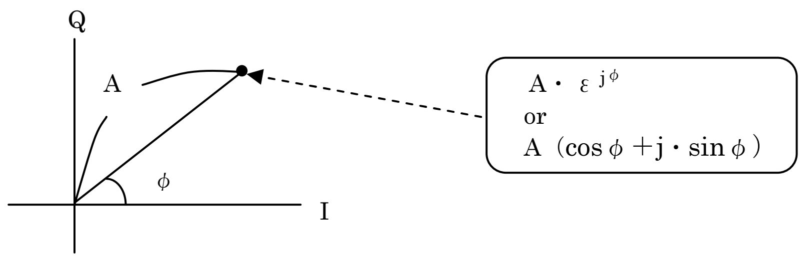
According to above figure, the positive frequency and negative frequency components of the real signal are shifted upward. If negative frequency component is shifted to become positive frequency component, the output signal includes only positive frequency component. That is, it is an orthogonal signal.

Therefore, amplitude change and phase change can be distinguished independently.

IQ orthogonal display

The complex signal is expressed by orthogonal coordinates of the real and imaginary parts.

- Real axis : expressed by I. "I" means "in-phase".
- Imaginary axis : expressed by Q. "Q" means "quadrature".



Significance of IQ conversion

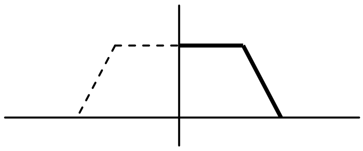
The IQ conversion extends or converts a real signal into a complex signal (orthogonal signal or analysis signal).

Significance 1 The bandwidth to be analyzed is doubled at the same sample frequency.

In complex signal, since the positive and negative frequencies are valid data respectively, the bandwidth is doubled compared with real signal.

Significance 2 The center frequency can be shifted to 0 Hz without influence of an image.

If LPF (low pass filter) is designed, it becomes BPF (band pass filter) automatically as shown figure below.



Significance 3 Instantaneous phase $\phi(t)$ can be measured.

$\phi(t)=\tan^{-1}[Q(t)/I(t)]$ @Horizontal axis: time

Significance 4 Instantaneous frequency $f(t)$ can be measured.

Phase $\phi(t)=\omega t$

$=2\pi f(t)t$

If phase $\phi(t)$ is differentiated with time,

$d\phi(t)/dt=2\pi f(t)$ however, it is assumed that there is little change of $f(t)$ to the time t.

$\therefore$ $f(t)=(1/2\pi)\,d\phi(t)/dt$

Because of $2\pi=360°$, $d\phi(t)=\phi n-\phi n\text{-}1$ (ϕn:instantaneous phase, $\phi n\text{-}1$:previous phase) and dt=Ts(sampling rate);

$\therefore$ $f(t)=(\phi n-\phi n\text{-}1)/360Ts$ @Horizontal axis: time

※ Sampling rate Ts (1/ f s)

f s : 34MHz @20MHz span

17MHz @10MHz span

∫

Significance 5 Instantaneous power $P(t)$ can be measured.

$P(t)=[I(t)^2+Q(t)^2]/50$ @Horizontal axis: time

Expressing modulation and demodulation of communication by IQ

As mentioned in above description, if the real signal is converted into IQ, it became clear that a complex Fourier transform can be performed, and also that the time domain analyses such as phase vs time, frequency vs time and power vs time can be performed.

Well, let's consider the signal modulation in communication. The cosine wave of a carrier changes as follows in order to encode information.

Modulating signal $= \underline{Ac(t)} \cdot \cos(2\pi\ \underline{f\,c(t)}\ t + \underline{\phi(t)})$

↑ Amplitude modulation ↑ Frequency modulation ↑ Phase modulation

When the above equation is converted into IQ ;

$$\begin{cases} I = Ac(t) \cdot \cos\{2\pi\ f\,c(t)\ t + \phi(t)\} \cdot \cos\omega t \\ \quad = Ac(t)/2 \cdot [\cos\{(\omega+\omega c)t+\phi(t)\}+\cos\{(\omega-\omega c)t-\phi(t)\}] \quad \text{however, } 2\pi\ f\,c(t)=\omega c \\ Q = Ac(t) \cdot \cos\{2\pi\ f\,c(t)\ t + \phi(t)\} \cdot \sin\omega t \\ \quad = Ac(t)/2 \cdot [\sin\{(\omega+\omega c)t+\phi(t)\}+\sin\{(\omega-\omega c)t-\phi(t)\}] \quad \text{however, } 2\pi\ f\,c(t)=\omega c \end{cases}$$

⇩ If the frequency of higher band is cut by LPF (low pass filter) located at later stage,

$$\begin{cases} I = Ac(t)/2 \cdot \cos\{(\omega-\omega c)t-\phi(t)\} \\ Q = Ac(t)/2 \cdot \sin\{(\omega-\omega c)t-\phi(t)\}] \end{cases}$$

(1) Amplitude modulated wave (AM)

If $\omega=\omega c$ and $\phi(t)=0$;

$$\begin{cases} I = Ac(t)/2 \\ Q = 0 \end{cases}$$

∴ AM signal $Ac(t)=2\times I$

(2) Frequency modulated wave (FM)

If $Ac(t) = A$ (constant), $\omega c = \omega - \Delta\omega$ ($\Delta\omega$: signal wave) and $\phi(t)=0$;

$$\begin{cases} I = A/2 \cdot \cos\Delta\omega \\ Q = A/2 \cdot \sin\Delta\omega \end{cases}$$

$$\begin{aligned} \tan^{-1}(Q/I) &= \tan^{-1}(\sin\Delta\omega / \cos\Delta\omega) \\ &= \tan^{-1}(\tan\Delta\omega) \\ &= \Delta\omega \quad (=2\pi\ \Delta f) \end{aligned}$$

∴ FM signal $\Delta f = (1/2\pi) \times \tan^{-1}(Q/I)$

(3) Phase modulated wave (PM)

If $Ac(t)=A$(constant) and $\omega=\omega c$;

$$\begin{cases} I = A/2 \cdot \cos\phi(t) \\ Q = -A/2 \cdot \sin\phi(t) \end{cases}$$

$$\begin{aligned} \tan^{-1}(Q/I) &= \tan^{-1}(-\sin\phi(t) / \cos\phi(t)) \\ &= \tan^{-1}(-\tan\phi(t)) \\ &= -\phi(t) \end{aligned}$$

∴ PM signal $\phi(t) = -\tan^{-1}(Q/I)$