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Design of Dielectric Detector for FRP Hot Stick in EHV Live line Maintenance

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Abstract: This paper presents an approach to detect the dielectric condition of FRP Hot Stick in EHV high voltage cable whereas shutting down the power system is not necessary. The radio frequency generating method is adopted by transmitting radio wave into the Electrodes. This instrument is small, easy to use and also inexpensive. Furthermore, the impurity level of dirt on high voltage insulator (non-ceramic type) will be analyzed by using the methods based on IEEE Std.978-1984 at 105 kV.DC. /305 mm. and OSHA Regulation 1910.269 Part J – live line tools. The frequency at 10-20 MHz is applied to FRP Hot Stick via Electrode1 and from FRP Hot Stick surface to Electrode 2. After that the results will be evaluated by testing in each condition of FRP Hot Stick, such as dry surface, hot surface, foil winding and conductor inserting. Finally, the watt loss will be examined and compared with the loss from humidity and Carbon tracking. The important components of this system are radio frequency generating unit, frequency stabilizing unit, frequency amplifier, FRP Hot Stick frequency counter, processing unit, and display unit.

Keywords: FRP Hot Stick, Live Line Maintenance, Watt-loss, Frequency, Maintenance, Electrode

1. INTRODUCTION

In the Extra High Voltage (EHV) system, the equipment, such as FRP Hot Stick and rope, are necessary for Live Line maintenance that is extremely risky for operators. Hence, all equipment should be checked for the dielectric characteristic to ensure that the international standard is met. This paper presents the approach to detect the FRP Hot Stick condition to prevent Flash Over at FRP Hot Stick surface under specified standards [1] and [2].

2. METHOD AND THORY

To define the dielectric condition of FRP Hot Stick, the frequency at 10 - 20 MHz is generated and applied to FRP Hot Stick Surface via Electrode 1 and finally transmitted to Electrode 2. The frequency at Electrode 2 will be measured and compared with the transmitted frequency to examine the watt-loss stemming from humidity or Carbon Tracking. If the quality of FRP Hot Stick does not meet the standard, LED and Buzzer will monitor the result to indicate that cleaning is required before use.

3. DESIGN OF THE SYSTEM

The important components of this system are frequency generating unit, frequency stabilizing unit, frequency amplifier, FRP Hot Stick frequency counter, processing unit, and display unit as shown in Fig. 1.

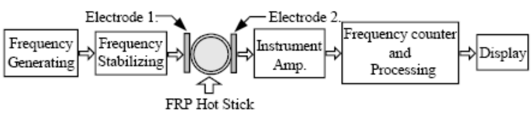


Fig. 1 Block diagram of the system

3.1 Frequency Generating Unit

Frequency Generating Unit provides 10 MHz frequency by using electronic circuit and then transmits into FRP Hot Stick via Electrode 1 and 2. This unit consists of IC#CD40106B and MC 14013D Dual Type D flip-flop as shown in Fig. 2.

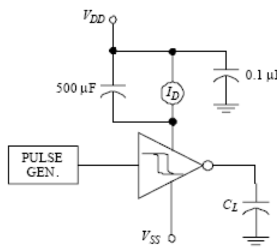


Fig. 2 Frequency Generating Unit with IC#CD40106B

3.2 Frequency Stabilizing Unit

IC#LM158, the Operation Amplifier for stabilizing or controlling frequency level from frequency generating unit, is applied to detect the watt-loss with high efficiency as shown in Fig. 3.

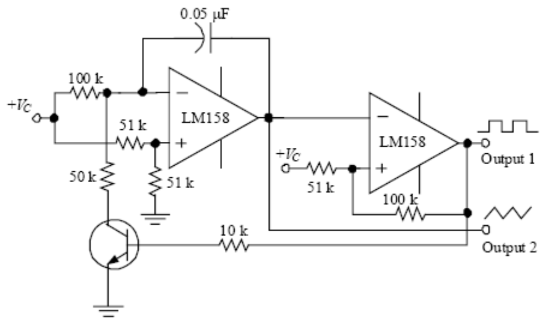


Fig. 3 Frequency Stabilizing Unit

3.3 Frequency Multiplication

The Schmitt Trigger circuit is used as the frequency multiplication circuit at maximum input current (I_{in}) = 100nA when $V_{DD} = 18V$, $T_A = 25°C$. The circuits are as shown in Fig. 4 and 5.

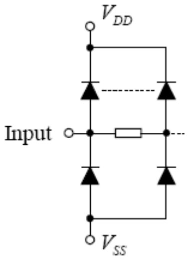


Fig. 4 Input Equivalent Circuit

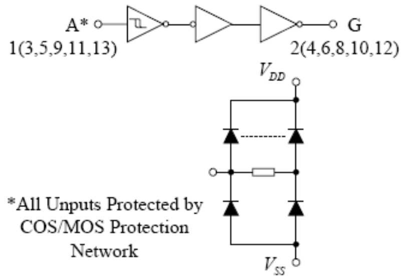


Fig. 5 Logic Diagram

3.4 Processing Unit

In this unit, the detected frequency will be compared with the determined value by using IC#CA3140A as shown in Fig. 6.

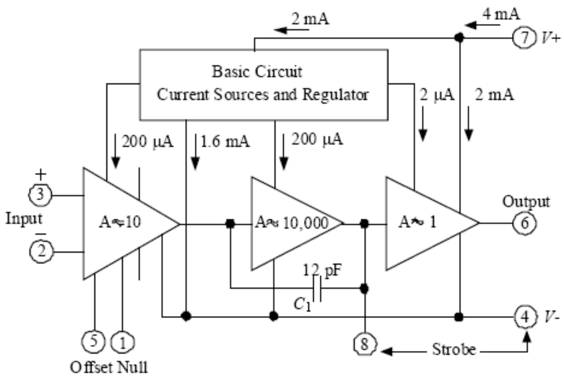


Fig. 6 Block Diagram of IC # CA3140

3.5 Display Unit

LED is used to monitor the dielectric condition of FRP Hot Stick. If it is dielectric, LED will turn to green. In contrast, red will be shown and buzzer will be alert if FRP Hot Stick is not in good condition.

4. EXPERIMENTS

This approach is developed to examine FRP Hot Stick in various conditions by detecting frequency from Electrode 1 and 2 and then the watt-loss will be evaluated. Here, the experiment is divided into 4 conditions of FRP Hot Stick: Dry surface, Wet surface, Foil winding and Conductor inserting.

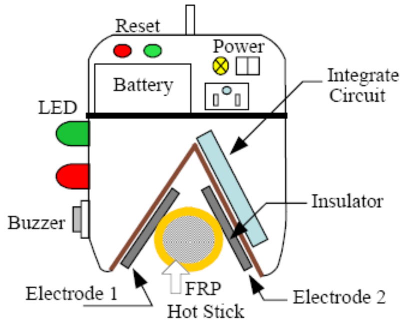


Fig. 7 Dielectric Detector for FRP Hot Stick

4.1 Dry Surface

4.1.1 Rectangular stainless conductors size 21.5 cm. x 6.5 cm. are attached to Electrode 1 and 2 that are located in different side. Then, the dielectric condition of dry surface FRP hot Stick is examined. The result is dielectric as shown in Fig. 8.

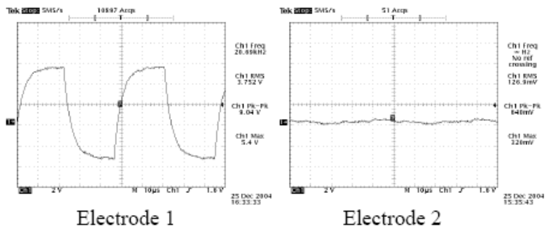


Fig. 8 Waveform obtained by using Stainless Conductor

4.1.2 When Pilot FRP Hot Stick is inserted between Electrode 1 and 2, LED turns to green. So, the condition is dielectric.

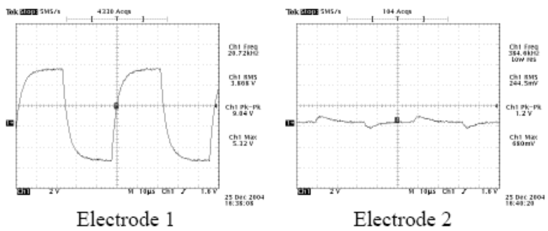
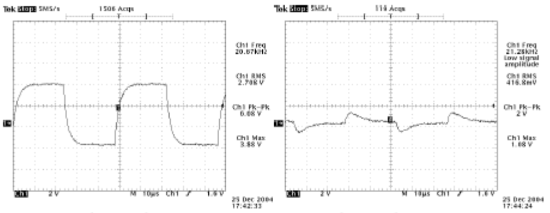


Fig. 9 Waveform obtained by using Pilot

4.2 Wet Surface

Water is sprayed to FRP Hot Stick surface. Then, LED turns to red or the condition is non-dielectric.

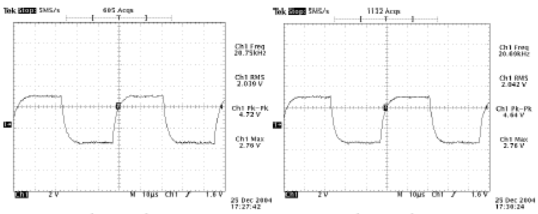


Electrode 1 Electrode 2

Fig. 10 Waveform obtained from wet-surface FRP Hot Stick

4.3 Foil Winding

1 cm. width foil is winded around FRP Hot Stick with 7.6 cm. distance. Then, non-electric condition is shown.

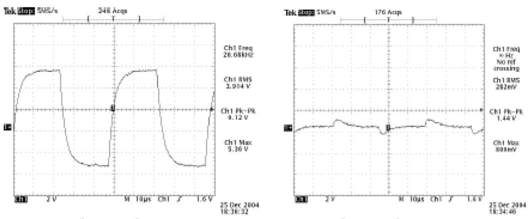


Electrode 1 Electrode 2

Fig. 11 Waveform obtained by winding foil

4.4 Conductor Inserting

A conductor with 2.5 mm. diameter is inserted into FRP Hot Stick. Then, dielectric condition is monitored.



Electrode 1 Electrode 2

Fig. 12 Waveform obtained by inserting conductor

5. EXPERIMENTAL RESULTS

From experiments, two conditions are indicated non-dielectric condition: foil winding and wet surface whereas dry surface and conductor inserting are illustrated dielectric condition. However, the frequencies and voltages measured from both Electrodes in dielectric condition are quite different because frequency and electrical voltage can not be transmitted when the surface is dry and clean. The comparison of measured frequencies and voltages from Electrode 1 and 2 are as shown in Table 1 and 2.

Table 1 Frequency Measured from Electrode 1 and 2

	Hot Stick Condition	Dry	Foil	Steel	Wet	Water inner
Frequency (MHz)	Electrode 1	20.72	20.69	20.74	20.78	20.74
	Electrode 1	384.6	20.68	72.46	∞	72.46
	Δ Frequency	363.88	0.01	51.72	∞	51.72

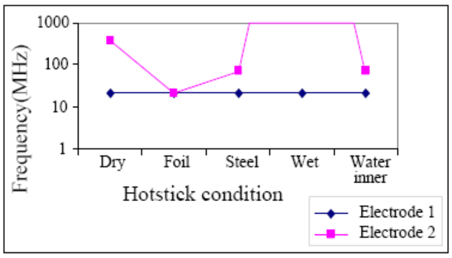


Fig. 13 Graph of frequency measured at Electrode 1 and 2

Table 2 Voltage Measured from Electrode 1 and 2

	Hot Stick Condition	Dry	Foil	Steel	Wet	Water inner
Voltage (V_{P-P})	Electrode 1	9.04	5.06	9.04	9.12	9.04
	Electrode 1	1.2	4.72	1.44	1.52	1.44
	Δ Voltage	7.84	0.96	7.6	7.6	7.6

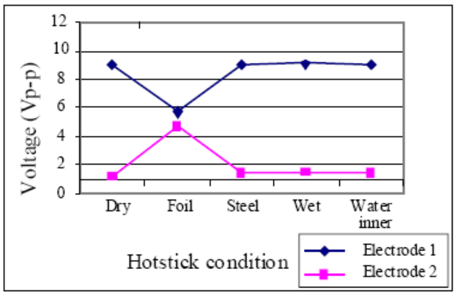


Fig. 14 Graph of Voltage measured at Electrode 1 and 2

6. CONCLUSION

In conclusion, the approach developed to detect dielectric condition of FRP Hot Stick provides the satisfactory ability. Two conditions indicated as non-dielectric are wet surface condition and foil winding. Those two conditions refer to humid and dirty surface that can cause non-dielectric condition of FRP Hot Stick. When FRP Hot Stick is not under the specification, cleaning and testing are required based on IEEE 978-1984 Standard at 105 kV.DC/305 mm. for safety reason. This approach will be then developed to measure humidity in high voltage cable of EHV system and detect the impurity level of dirt on high voltage insulator (non-ceramic type).

REFERENCES

[1] Department of Labor, OSHA, 29 CFR PART 1910; Federal Register, Vol.59, No. 20, January 31, 1994, Rules & Regulations.

[2] IEEE Standard 978-1984, Guide for In-Service Maintenance & Electrical Testing of Live Line Tools.

[3] ASTM F711-89, Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube used in Live-Line Tools.

[4] W. McDermid, J.C Bromley , D.J. Dodds, D.R. Swatek, "Investigation of the Flashover of a FRP Hot Stick While in Use for Live Line Work at 500 kV" , IEEE Transaction on Power Delivery, Vol.14,No. 3, July 1999 , pp 1158-1166.

[5] W. McDermid, J.C Bromley, D.R. Swatek, "FRP Hot Stick Flashover during EHV Live Line Work" , IEEE Transaction on Power Delivery,2003.

[6] ASTM F711-89, Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube used in Live-Line Tools.

ภาคผนวก ข
คู่มือคุณสมบัติของแผงวงจรรวมที่ใช้ในการออกแบบตัวตรวจสอบอุปกรณ์ที่ใช้ทำงานกับระบบไฟฟ้าแรงสูงสำหรับการทำงานโดยไม่ปิดระบบการจ่ายไฟ

1. รายละเอียดต่างๆของ IC Op-Amp เบอร์ LM158

Electrical Characteristics V^{+} = +5.0V, unless otherwise stated

Parameter	Conditions	LM158A			LM358A			LM158/LM258			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 7), $T_A = 25^{\circ}C$		1	2		2	3		2	5	mV
Input Bias current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25^{\circ}C$, V_{CM} = OV, (Note 8)		20	50		45	100		45	150	nA
Input offset current	$I_{IN(+)} - I_{IN(-)}, V_{CM} = OV, T_A = 25^{\circ}C$		2	10		5	30		3	30	nA
Input Common-Mode Voltage Range	V^{+} = 30V, (Note 9) (LM2904 V^{+} =26V), T_A = $25^{\circ}C$	0		$V^{+}-1.5$	0		$V^{+}-1.5$	0		$V^{+}-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps V^{+} =30V (LM2904 V^{+} =26V) V^{+} =5V		1 0.5	2 1.2					1 0.5	2 1.2	mA mA

Electrical Characteristics V^{+} = +5.0V, unless otherwise stated								
Parameter	Conditions	LM358			LM2904			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 7), $T_A = 25^{\circ}C$		2	7		2	7	mV
Input Bias current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25^{\circ}C$, V_{CM} = OV, (Note 8)		45	250		45	250	nA
Input offset current	$I_{IN(+)} - I_{IN(-)}, V_{CM} = OV, T_A = 25^{\circ}C$		5	50		5	50	nA
Input Common-Mode Voltage Range	V^{+} = 30V, (Note 9) (LM2904 V^{+} =26V), T_A = $25^{\circ}C$	0		$V^{+}-1.5$			$V^{+}-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps V^{+} =30V (LM2904 V^{+} =26V) V^{+} =5V		1 0.5	2 1.2		1 0.5	2 1.2	mA mA

Electrical Characteristics

V^+ = +5.0V,(Note 6), unless otherwise stated

Parameter	Conditions	LM158A			LM358A			LM158/LM258			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	$V^+=15V, T_A=25^\circ C$, $R_L \geq 2k\Omega$, (For V_O = 1V to 11V)	50	100		25	100		50	100		V/mv
Common-Mode Rejection Ratio	$T_A=25^\circ C$, $V_{CM}=0V$ to $V^+-1.5V$	70	85		65	85		70	85		dB
Power Supply Rejection Ratio	V^+=5V to 30V (LM2904, V^+=5V to 26v), $T_A=25^\circ C$	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling	F=1 kHz to 20 kHz, $T_A=25^\circ C$ (Input Referred), (Note 10)		-120			-120			-120		dB
Output Current — Source	$V_{IN}+$=1V, $V_{IN}-$=0V, V^+ = 15V, V_O=2V, $T_A=25^\circ C$	20	40		20	40		20	40		mA
Output Current — Sink	$V_{IN}-$=1V, $V_{IN}+$=0V V^+=15V, $T_A=25^\circ C$, V_O=2V	10	20		10	20		10	20		mA
	$V_{IN}-$=1V, $V_{IN}+$=0V $T_A=25^\circ C$, V_O=200Mv, V^+=15V	12	50		12	50		12	50		μA
Short Circuit to Ground	$T_A=25^\circ C$,(Note 4) V^+=15V		40	60		40	60		40	60	mA
Input Offset Voltage	(Note 7)			4			5			7	mV
Input Offset Voltage Drift	$R_S=0\Omega$		7	12		7	20		7		$\mu V/^\circ C$
Input offset Current	$I_{IN(+)}-I_{IN(-)}$			30			75			100	nA
Input offset Current Drift	$R_S=0\Omega$		10	200		10	300		10		$pA/^\circ C$
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$		40	100		40	200		40	300	nA
Input Common-Mode Voltage Rage	V^+ = 30 V, (Note 9) (LM2940, V^+ =26V)	0		V^+-2	0		V^+-2	0		V^+-2	V

Electrical Characteristics (Continued)

V^+ = +5.0V, (Note 6), unless otherwise stated

Parameter		Conditions		LM158A			LM358A			LM158/LM258			Units
				Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		V^+ =+15V (V_o = 1V to 11V) $R_L \geq 2k\Omega$		25			15			25			V/mV
Output Voltage Swing	V_{OH}	V^+ = +30V (LM2940, V^+ =26 V)	$R_L = 2k\Omega$	26			26			26			V
			$R_L = 10k\Omega$	27	28		27	28		27	28		V
	V_{OL}	V^+ = 5V, $R_L = 10k\Omega$			5	20		5	20		5	20	mv
Output Current	Source	$V_{IN}+$ = +1V, $V_{IN}-$ =0V, V^+ = 15V, V_o = 2V		10	20		10	20		10	20		mA
	Sink	$V_{IN}-$ =+1V, $V_{IN}+$ = 0V, V^+ =15V, V_o = 2v		10	15		5	8		5	8		mA

Electrical Characteristics

V^+ = +5.0V, (Note 6), unless otherwise stated

Parameter		Conditions	LM358			LM2904			Units
			Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V, T_A = 25^\circ C$, $R_L \geq 2k\Omega$, (For V_o = 1V to 11V)	25	100		25	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25^\circ C$, $V_{CM} = 0V$ to $V^+ - 1.5V$	65	85		50	75		dB
Power Supply Rejection Ratio		V^+ =5V to 30V (LM2904, V^+ =5V to 26v), $T_A = 25^\circ C$	65	100		50	100		dB
Amplifier-to-Amplifier Coupling		F=1 kHz to 20 kHz, $T_A = 25^\circ C$ (Input Referred), (Note 10)		-120			-120		dB
Output Current	Source	$V_{IN}+$ =1V, $V_{IN}-$ =0V, V^+ = 15V, V_o =2V, $T_A = 25^\circ C$	20	40		20	40		mA
	Sink	$V_{IN}-$ =1V, $V_{IN}+$ =0V V^+ =15V, $T_A = 25^\circ C$, V_o =2V	10	20		10	20		mA
		$V_{IN}-$ =1V, $V_{IN}+$ =0V $T_A = 25^\circ C$, V_o =200Mv, V^+ =15V	12	50		12	50		μA

Short Circuit to Ground	$T_A = 25^{\circ}C$,(Note 4) V^{+}=15V		40	60		40	60	mA
Input Offset Voltage	(Note 7)			9			10	mV
Input Offset Voltage Drift	$R_S = 0\Omega$		7			7		$\mu V/^{\circ}C$
Input offset Current	$I_{IN(+)} - I_{IN(-)}$			150		45	200	nA
Input offset Current Drift	$R_S = 0\Omega$		10			10		$pA/^{\circ}C$
Input Bias Current	$I_{IN(+)} or I_{IN(-)}$		40	500		40	500	nA
Input Common-Mode Voltage Rage	V^{+} = 30 V, (Note 9) (LM2940, V^{+} =26V)	0		$V^{+}-2$	0		$V^{+}-2$	V

Parameter		Conditions		LM358			LM2904			Units
				Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		V^{+} =+15V (V_o = 1V to 11V) $R_L \geq 2k\Omega$		15			15			V/mV
Output Voltage Swing	V_{OH}	V^{+} =+30V (LM2940,V^{+} =26V)	$R_L = 2k\Omega$	26			22			V
			$R_L = 10k\Omega$	27	28		23	24		V
	V_{OL}	V^{+}= 5V, $R_L = 10k\Omega$			5	20		5	100	mv
Output Current	Source	$V_{IN}+$= +1V, $V_{IN}-$ =0V, V^{+}= 15V, V_o = 2V		10	20		10	20		mA
	Sink	$V_{IN}-$ =+1V, $V_{IN}+$= 0V, V^{+} =15V, V_o = 2v		5	8		5	8		mA

Electrical Characteristics (Note 15)

For the 331

Parameter	Conditions	Min	Typ	Max	Units
Input Offset Voltage (Note16)	$T_A = 25^{\circ}C$，$R_S \leq 50K$		2.0	7.5	mV
Input Offset Current (Note16)	$T_A = 25^{\circ}C$		6.0	50	nA
Input Bias Current	$T_A = 25^{\circ}C$		100	250	nA
Voltage Gain	$T_A = 25^{\circ}C$	40	200		V/mV
Response Time (Note17)	$T_A = 25^{\circ}C$		200		ηS
Saturation Voltage	$V_{IN} \leq -10mV$，$I_{OUT} = 50mA$ $T_A = 25^{\circ}C$		0.75	1.5	V
Strobe ON Current (Note 18)	$T_A = 25^{\circ}C$		2.0	5.0	mA
Output Leakage Current	$V_{IN} \geq -10mV$，$V_{OUT} = 35mA$ $T_A = 25^{\circ}C$，$I_{STROBE} = -3mA$ V^{-} = Pin 1 = -5V$V_{OUT} \leq 8mA$		0.2	50	nA
Input Offset Voltage (Note16)	$R_S \leq 50K$			10	mA
Input Offset Current (Note16)				70	nA

Input Bias Current				300	nA
Input Voltage Range		-14.5	13.8,-14.7	13.0	V
Saturation Voltage	$V^+ \geq 4.5V$, $V^- = 0$ $V_{IN} \leq$ 10mV ,		0.23	0.4	V
Positive Supply Current	$T_A = 25^{\circ}C$		5.1	7.5	mA
Negative Supply Current	$T_A = 25^{\circ}C$		4.1	5.0	mA

PARAMETER	SYMBOL	TEST CONDITIONS		TYPICAL VALUES		UNITS
Input Offset Voltage Adjustment Resistor		Typical Value of Resistor Between Terminals 4 and 5 or 4 and 1 to Adjust Max VIO		4.7	18	kΩ
Input Resistance	RI			1.5	1.5	TΩ
Input Capacitance	CI			4	4	pF
Output Resistance	RO			60	60	Ω
Equivalent Wideband Input Noise Voltage (See Figure 27)	eN	BW = 140kHz, RS = 1MΩ		48	48	µV
Equivalent Input Noise Voltage (See Figure 35)	eN	RS = 100Ω	f = 1kHz	40	40	nV/√Hz
			f = 10kHz	12	12	nV/√Hz
Short Circuit Current to Opposite Supply	IOM+		Source	40	40	mA
	IOM		Sink	18	18	mA
Gain-Bandwidth Product, (See Figures 6, 30)	fT			4.5	4.5	MHz
Slew Rate, (See Figure 31)	SR			9	9	V/µs
Sink Current From Terminal 8 To Terminal 4 to Swing Output Low				220	220	µA
Transient Response (See Figure 28)	tr	RL = 2kΩ CL = 100pF	Rise Time	0.08	0.08	µs
	OS		Overshoot	10	10	%
Settling Time at 10VP-P, (See Figure 5)	tS	RL = 2kΩ CL = 100pF Voltage Follower	To 1mV	4.5	4.5	µs
			To 10mV	1.4	1.4	µs

2.Electrical Specifications for Equipment Design, at VSUPPLY = ±15V, TA = 25 ^{o}C, unless Otherwise Specified

PARAMETER	SYMBOL	CA3140			CA3140A			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	|VIO|	-	5	15	-	2	5	mV
Input Offset Current	|IIO|	-	0.5	30	-	0.5	20	pA
Input Current	II	-	10	50	-	10	40	pA
Large Signal Voltage Gain (Note 3) (See Figures 6, 29)	AOL	20	100	-	20	100	-	kV/V
		86	100	-	86	100	-	dB