CS615 Water Content Reflectometer

User Guide

Issued 24.9.01

Copyright © 2001 Campbell Scientific, Inc. Copied Under Licence by Campbell Scientific Ltd.

Guarantee

This equipment is guaranteed against defects in materials and workmanship. This guarantee applies for twelve months from date of delivery. We will repair or replace products which prove to be defective during the guarantee period provided they are returned to us prepaid. The guarantee will not apply to:

- Equipment which has been modified or altered in any way without the written permission of Campbell Scientific
- Batteries
- Any product which has been subjected to misuse, neglect, acts of God or damage in transit.

Campbell Scientific will return guaranteed equipment by surface carrier prepaid. Campbell Scientific will not reimburse the claimant for costs incurred in removing and/or reinstalling equipment. This guarantee and the Company's obligation thereunder is in lieu of all other guarantees, expressed or implied, including those of suitability and fitness for a particular purpose. Campbell Scientific is not liable for consequential damage.

Please inform us before returning equipment and obtain a Repair Reference Number whether the repair is under guarantee or not. Please state the faults as clearly as possible, and if the product is out of the guarantee period it should be accompanied by a purchase order. Quotations for repairs can be given on request.

When returning equipment, the Repair Reference Number must be clearly marked on the outside of the package.

Note that goods sent air freight are subject to Customs clearance fees which Campbell Scientific will charge to customers. In many cases, these charges are greater than the cost of the repair.



Campbell Scientific Ltd, Campbell Park, 80 Hathern Road, Shepshed, Loughborough, LE12 9GX, UK Tel: +44 (0) 1509 601141 Fax: +44 (0) 1509 601091

Email: support@campbellsci.co.uk www.campbellsci.co.uk

1. Description and Principle of Operation
2. Specifications
2.1 Dimensions22.2 Weight22.3 Electrical Specifications2
3. Performance Specifications 2
3.1 Accuracy23.2 Resolution23.3 Operating Range33.3.1 Soil Electrical Conductivity33.3.2 Soil Organic Matter and Clay Content33.3.3 Cable length43.3.4 Temperature Dependence4
4. Installation
4.1 Orientation
5. Wiring 5
6. Datalogger Instructions5
6.1 Introduction56.2 Pulse Count66.2.1 Simple program to Demonstrate the Use of Pulse CountInstruction with CS61566.3 Period Measurement7
7. Maintenance
8. Calibration
8.1 General
9. Sample Programs9
 9.1 Simple Program Using the Period Measurement Instruction (P27) of a Datalogger to Read a Single CS615

Apper	Avoiding A-1	
	A.1 Introduction	A-1
	A.2 Minimising General Interference	A-1
	A.3 Minimising Problems within a Measurement System	A-1
Figures		
	1. CS615 Water Content Reflectometer	1
	2. CS615 Calibration Curves	8
	3. Wiring Configuration for Multiplexing 48 CS615s with	
	AM416 and Various Dataloggers	17
Tables		
	1. Instruction 3 Pulse Count Measurement	6

CS615 Water Content Reflectometer

The CS615 Water Content Reflectometer measures the volumetric water content of porous media using time-domain measurement methods. Its output can be connected to a range of Campbell Scientific's dataloggers to provide the required output.

This User Guide covers version 8221-07 of the CS615 (the version number appears on a label on the cable).

1. Description and Principle of Operation

The Water Content Reflectometer consists of two stainless steel rods connected to a printed circuit board. A shielded 4-conductor cable is connected to the circuit board to supply power, enable the probe and monitor the pulse output. The circuit board is potted in an epoxy block.

The reflectometer uses time-domain methodology to derive water content information from the effect of a changing dielectric constant on the propagation velocity of electromagnetic waves along a wave guide. The resulting output can be transmitted to all current Campbell Scientific dataloggers for storage and conversion to volumetric water content using calibration values.¹

High speed electronic components on the circuit board are configured as a bistable multivibrator. The output of the multivibrator is connected to the probe rods which act as a wave guide. When the multivibrator switches states, the transition travels the length of the rods and is reflected by the rod ends. This reflection provides feedback to switch the state of the multivibrator. The travel time to the end of the rods and back is dependent on the dielectric constant of the material surrounding the rods. The dielectric constant is predominantly dependent on the water content. Digital circuitry scales the multivibrator output to an appropriate frequency for measurement with a datalogger. The CS615 output is essentially a square wave with an amplitude swing of ± 2.5 V DC. The frequency or period of the square wave is used for the calibration of water content.



Figure 1 CS615 Water Content Reflectometer

¹ See Appendix A for information on how to minimise problems due to electromagnetic interference.

2. Specifications

2.1 Dimensions

Rods:	300mm long
	3.2mm diameter
	32mm spacing
Head:	110 x 63 x 20mm

2.2 Weight

Probe: 280g Cable: 35gm⁻¹

2.3 Electrical Specifications

Power Consumption

70 milliamps @ 12V DC when enabled, less than 10 microamps quiescent

Power Supply Voltage

9V DC minimum, 18V DC maximum

Enabling Voltage

Minimum voltage to enable the probe is 1.3V DC

3. Performance Specifications

3.1 Accuracy

The nominal first-order calibration provides accuracy better than $\pm 4\%$ for volumetric water contents less than 12%. The accuracy is $\pm 3\%$ over the range of 12% water content to saturation. The accuracy when using the general calibrations depends on soil texture and mineral composition. These nominal accuracy figures can be improved when using calibration for a specific type of soil.

See the section on calibration (Section 8) for a more detailed discussion of accuracy.

3.2 Resolution

The resolution for volumetric water content depends on which datalogger instruction is used to measure the output of the probe. When the CR10/10X, CR500/510 or CR23X Instruction 27, Period Measurement, is used, the resolution is approximately 10^{-6} m³m⁻³ and is not a factor. (Period measurement is not available on the CR7 and 21X dataloggers.)

When Instruction 3, Pulse Count, is used, the resolution with an execution interval of 1.0 second is 10^{-4} m³m⁻³ when the pulse period is 1.3 milliseconds. The resolution improves (i.e. decreases linearly) both as the water content decreases and as the execution interval increases. An execution interval of 0.1 second yields a resolution of 10^{-2} m³m⁻³ at the same water content.

3.3 Operating Range

3.3.1 Soil Electrical Conductivity

The quality of soil moisture measurement methods which apply electromagnetic fields to wave guides is affected by soil electrical conductivity. The propagation of electromagnetic fields in the configuration of the CS615 is predominantly affected by changing dielectric constant due to changing water content, but is also affected by electrical conductivity. Free ions in soil solution provide electrical conduction paths which result in attenuation of the signal applied to the waveguides. This attenuation both reduces the amplitude of the high-frequency signal on the probe rods and affects the shape of the oscillating signal. The attenuation reduces oscillating frequency at a given water content because it takes a longer time to reach the oscillator trip threshold.

Soil electrical conductivity can be described by (Rhoades et al., 1976):

 $\sigma_{bulk} = \sigma_{solution} \theta_v T + \sigma_{solid}$

where σ is the electrical conductivities of the bulk soil, the soil solution and the solid constituents, θ_v is the volumetric water content, and T is a soil-specific transmission coefficient intended to account for the tortuosity of the flow path as water content changes. (See Rhoades et al, 1989, for a form of this equation which accounts for mobile and immobile water.) The above equation is presented here to show the relationship between soil solution electrical conductivity and soil bulk electrical conductivity.

Soil solution electrical conductivity, $\sigma_{solution}$ can be determined in the laboratory using extraction methods. Soil bulk electrical conductivity can be measured using time domain reflectometry (TDR) methods. Most expressions of soil electrical conductivity are given in terms of solution conductivity. Discussion of the effects of soil electrical conductivity on CS615 performance will be on a soil solution basis unless stated otherwise.

When soil solution electrical conductivity values exceed 1dSm⁻¹, the slope of the calibration begins to change. The slope decreases with increasing electrical conductivity. The probe will still respond to water content changes with good stability, but the calibration will have to be modified – see Calibration section. For soils with high electrical conductivity, a unique calibration will need to be generated for the particular soil. The probe output can become unstable at electrical conductivity values greater than 5dSm⁻¹.

3.3.2 Soil Organic Matter and Clay Content

The amount of organic matter and clay in a soil can alter the response of dielectric-dependent methods to changes in water content. This is apparent when mechanistic models are used to describe this measurement methodology.

The electromagnetic energy introduced by the probe acts to re-orientate or polarise the water molecules which are polar. If other forces are acting on the polar water molecules, the force exerted by the applied signal will be less likely to polarise it. This has the net effect of 'hiding' some of the water from the probe.

Organic matter and most clays are highly polar. Additionally, some clays sorb water interstitially and thus inhibit polarisation by the applied field. It would be convenient if the calibration of water content to CS615 output period could be adjusted according to some parameter of the soil which reflects the effect of the intrinsic forces. However, identification of such a parameter has not been done,

and it is likely that measurement of the correlation parameter would be more difficult than calibrating the CS615 for a given soil.

3.3.3 Cable Length

Probe cable length is not a limitation under typical applications. Laboratory measurements show no degradation in measurement quality with cable lengths up to 100 metres. Cable lengths greater than 50m may increase the potential for damage from electrostatic discharge (lightning). The performance may be degraded if cable other than that provided with the probe is used.

NOTE Larger distances between the datalogger and the CS615 can be achieved by the use of junction boxes and additional protective earth rods — please contact Campbell Scientific for further advice.

NOTE Adequate lightning protection depends on the datalogger having a good earth ground to provide a low resistance path to a point of low potential. See your datalogger manual for further details.

3.3.4 Temperature Dependence

The CS615 output is sensitive to temperature, and compensation can be applied to enhance accuracy. The magnitude of the temperature coefficient varies with water content. Laboratory measurements were performed at various water contents and over the temperature range of 10°C to 30°C. The calibration shown in Section 8 is for a temperature of 20°C. The following equation can be used to interpolate the temperature coefficient for a range of volumetric water content (θ_{o}) values:

 $Coef_{temperature} = -3.46*10^{-4} + 0.019q_v - 0.045q_v^2$

To apply this correction, the following equation can be used:

 $\theta_{vcorrected} = \theta_{vuncorrected} - (T - 20) * Coef_{temperature}$

Application of this correction yields a maximum difference between corrected and uncorrected water content of approximately 1.6%. Considering the accuracy of the measurement and the potential spatial variability of soil temperature along the length of the probe rods, the correction is not necessary in most cases.

An example for using temperature correction is a measurement taken on a soil at a water content of about 0.23 and a temperature of 25°C. The temperature coefficient value is $0.00164 \text{m}^3 \text{m}^{-3} \text{ °C}^{-1}$ which means that the measured water content is 5°C *(0.00164 m³ m⁻³ °C⁻¹) or 0.8% high.

4. Installation

CAUTION

Operating the CS615 for prolonged periods (as necessary when using the pulse count measurement technique) or when enabling several probes simultaneously may cause interference with other CS615 probes or other equipment. Please refer to Appendix A before installing probes in the field. The method used for probe installation can affect the accuracy of the measurement. Ensure that the probe rods are kept as close to parallel as possible when installed to maintain the design wave guide geometry. The sensitivity of this measurement is greater in the regions closest to the rod surface than at distances away from the surface. Probes inserted in a manner which generates air voids around the rods will reduce the measurement accuracy. In some applications installation can be improved by using insertion guides or a pilot tool - contact Campbell Scientific for further details.

4.1 Orientation

The probe rods can be inserted vertically into the soil surface or buried at any orientation to the surface. A probe inserted vertically into the soil surface will give an indication of the water content in the upper 300mm of soil. You can also install the probe horizontal to the surface to detect the passing of wetting fronts or other vertical water fluxes, or install it at an angle. A probe installed at an angle of 30 degrees to the surface, for example, will give an indication of the water content of the upper 150mm of soil.

5. Wiring

Wire Colour	Function	CR10/10X	CR23X	21X/CR7 ¹
		CR500/510*		
red	12V DC supply	+12V	+12V	+12V
green	probe output	SE analogue	SE analogue	pulse channel
		channel	channel	
orange	enable	control port	control port	control port
black	ground	G		4
clear	shield (ground)	G	4	4

* The CR500/510 datalogger is normally programmed using Short Cut, and the wiring suggested by Short Cut should always be used.

NOTE

CS615s manufactured before 12/95 have the green and black leads reversed. Check the wiring label near the end of the cable.

The enable line is set high to put the probe in the measuring mode.

6. Datalogger Instructions

6.1 Introduction

The output of the CS615 is essentially a square wave with amplitude ± 2.5 V DC and a frequency which is dependent on the dielectric constant of the material surrounding the probe rods. The frequency range is approximately 600 to 1500Hz. The period (0.7 to 1.6 milliseconds) is used in the calibration for water content.

The Pulse Count Instruction of any datalogger can be used with the CS615 output connected to a pulse count channel. Since the Period Measurement Instruction gives better resolution, it should normally be used with suitable dataloggers with the CS615 output connected to a single-ended analogue channel.¹

¹ See Appendix A for information on how to minimise problems due to electromagnetic interference.

6.2 Pulse Count

CAUTION Operating the CS615 for prolonged periods (as necessary when using the pulse count measurement technique) or when enabling several probes simultaneously may cause interference with other CS615 probes or other equipment. Please refer to Appendix A before installing probes in the field.

It is important to understand the event sequence during the Instruction 3 Pulse Count Measurement when using it with the CS615. See the Instructions section of the datalogger manual for a detailed explanation of the Pulse Count instruction.

Table 1 Instruction 3 Pulse Count Measurement			
PARAM. NUMBER	DATA TYPE	DESCRIPTION	
01: 02: 03: 04: 05: 06:	2 2 2 4 FP FP	Repetitions Channel number for first measurement Configuration code (from table) Input location for first measurement Multiplier Offset	
Input locations altered: 1 per measurement			
Code	Configuration		
0 1 2 3 4 1X 2X	High frequency pulse Low level AC Switch closure High frequency pulse, sixteen bit counter Low level AC, sixteen bit counter Long interval data discarded Long interval data discarded, frequency (Hz) output		

A brief explanation of pulse count use in a CS615 application is presented here. The LOW LEVEL AC option for the configuration code is used, and the output is selected for frequency (Hz). Period (msec) is easily obtained with the Inverse instruction (42).

6.2.1 Simple Program to Demonstrate the Use of the Pulse Count Instruction with the CS615¹

*Ta	ble	1 Progr	am	
(01:	2.0	Execution Interval (seconds)	
1:	If	time is	(P92)	
	1:	0000	Minutes(Seconds) into a	
	2:	15	Interval (same units as above)	
	3:	30	Then Do	
2:	Do	(P86)	; set CS615 enable hig	h
	1:	41	Set Port 1 High	

¹ See Appendix A for information on how to minimise problems due to electromagnetic interference.

3:	Begi	.nning o	f Loop (P87)	
	1:	1	Delay	
	2:	2	Loop Count	
4:	End	(P95)		
5:	Puls	e (P3)		
	1:	1	Reps	
	2:	1	Pulse Input Channel	
	3:	21	Low Level AC, Output Hz	
	4:	1	Loc [kHz]	
	5:	.001	Mult	; convert Hz to kHz
	6:	0.0	Offset	
6:	Do (P86)		; set CS615 enable low
	1:	51	Set Port 1 Low	
7:	End	(P95)		
End	Prog	ram		

The Pulse Count instruction uses accumulators to monitor pulses on the datalogger Pulse Count Channels. At the beginning of each execution interval for the table containing the Pulse Count instruction, the accumulator count is dumped to a section in datalogger RAM, the accumulator is then reset to zero and begins accumulating counts again. When the Pulse Count instruction is reached, the value in RAM is modified by the multiplier and offset in the Pulse Count instruction and the result written to input storage. The RAM is then reset to zero.

Consider the simple program shown above. Additional instructions which might be needed for multiplexer control or other functions have been omitted for simplicity. This program is written to obtain a CS615 reading every 15 minutes.

When the program is compiled by the datalogger, the accumulators begin monitoring the Pulse Count Channels. Immediately following compilation by the datalogger, there is no signal on the input channels because the CS615 is not enabled until the 15 minute interval specified in the Instruction 92 is reached. When the 15 minute interval is reached, Instruction 86 is executed which sets the enable of the CS615 high and the probe outputs a signal which is detected by the pulse counters.

The Loop Instruction in this application uses a Delay of 1 and a Loop Count of 2. Program execution pauses during the first loop count until the execution interval of 2 seconds is complete. This delay is necessary because the probe has not been enabled for the entire execution interval which means a complete count is not obtained. More complex programs will contain additional instructions prior to the instruction to enable the CS615, and these instructions can take a significant amount of time to execute. During the second time through the Loop Instruction the pulse counters see the CS615 output for the full execution interval. At the end of this interval the accumulators transfer to RAM and are reset. When the program execution then moves to the Pulse Count Instruction (P3) the value in RAM is converted to kHz and written to input storage.

6.3 Period Measurement

The Period Measurement instruction (Instruction 27) is available on the CR10/10X, CR23X and CR500/510 dataloggers. This instruction should always be used, if possible, because it gives much better resolution than the Pulse Count instruction, although it is not a factor in the range of frequencies for the CS615.

See your Datalogger Manual for further details of Instruction P27.

7. Maintenance

The CS615 does not require periodic maintenance.

8. Calibration

8.1 General

The calibration information in this section applies only to the CS615 version 8221-07. The version number is listed on a label attached near to the end of the probe cable.

The CS615 provides an indirect measurement of soil water content by using the effect of a changing dielectric constant on applied electromagnetic waves. The probe rods act as a wave guide and the material (soil) surrounding the rods varies in dielectric constant value with the amount of water in the material.

The dielectric constant of the soil is a weighted summation of the dielectric constants of the soil constituents. The dielectric constant of water is significantly higher than that of other constituents. Changes in the dielectric constant of the soil system can be attributed to changes in water content. This is the basis for the measurement technique.

There are two soil properties which affect the response of the CS615 to changes in water content. High clay contents (greater than 30%) or high electrical conductivity (greater than $1dSm^{-1}$) may require that the calibration be adjusted or generated for the specific soil.



Figure 2 CS615 Calibration Curves

Figure 2 demonstrates the effect of electrical conductivity on the calibration. At electrical conductivity values of 1dSm⁻¹ and below, the calibration shown for 0.8 dS m⁻¹ works well for a wide range of soil textures. The calibration curves for the higher electrical conductivities show that the slope decreases with increasing conductivity. The response of the CS615 to changes in water content at higher electrical conductivity values is well-behaved up to approximately 5dSm⁻¹. The calibration can be approximated from figure 2 if the soil solution electrical conductivity is known or if soil measurements are made with the CS615 and the actual water content is independently determined. High clay content has a similar affect on the calibration but the magnitude is dependent on the clay type.

electrical conductivity (dS m ⁻¹)	calibration
≤1.0	$\theta_{\nu}(\tau) = -0.187 + 0.037 * \tau + 0.335 * \tau^2$
1.8	$\theta_{\nu}(\tau) = -0.207 + 0.097 * \tau + 0.288 * \tau^2$
3.0	$\theta_{\nu}(\tau) = -0.298 + 0.361 * \tau + 0.096 * \tau^2$

 θ_v is the volumetric water content on a fraction basis (0.20 is 20% volumetric water content) and, τ is the CS615 output period in milliseconds.

The calibration can be applied using a Polynomial Instruction (P55) as follows:

Polynomial (P55) ;convert period to water content

1:	1	Reps
2:	1	X Loc [615period]
3:	2	F(X) Loc [615water]
4:	-0.187	C0
5:	0.037	C1
6:	0.335	C2
7:	0.0	C3
8:	0.0	C4
9:	0.0	C5

NOTE

The accuracy figures obtained using soil-specific calibration only apply to unfrozen soil.

8.2 Calibration for a Specific Soil

The calibration relationship between volumetric water content and the CS615 output period for a specific soil may need to be established if increased accuracy is needed, or if the composition of the soil deviates from what might be considered typical. High electrical conductivity, high clay content, high quartz content and high organic matter content are conditions which will affect probe response.

9. Sample Programs

Four sample programs for the CS615 are provided below to illustrate its use with different datalogger types and accessories. Please refer to Appendix A for datalogger and pulse count restrictions within the EU due to EMC compliance regulations.

NOTE

The calibration coefficients in the example programs are typical values for demonstration purposes only. Please refer to the previous section on calibration for further information.

9.1 Simple Program Using the Period Averaging Instruction (P27) of a Datalogger to Read a Single CS615¹

This program determines volumetric water content hourly and writes the period and water content values to Final Storage.

Datalogger	CS615
Single-Ended Channel 1 (SE1)	green
Control Port 5 (C5)	orange

The red lead is connected to 12V DC and the black lead and shield are connected to ground (G on CR10/10X and \perp on CR23X).

For the CR500/510 datalogger, use the connections specified by Short Cut.

```
*
       Table 1 Program
01:
          5.0
                Execution Interval (seconds)
1:
   If time is (P92)
                                                 ;take reading hourly
   1: 0000
                Minutes (Seconds --) into a
   2:
        60
                Interval (same units as above)
   3:
        30
                Then Do
2:
  Do (P86)
   1:
                                                     ; enable CS615
        45
                Set Port 5 High
                                                      ; read CS615
3:
  Period Average (SE) (P27)
   1:
          1
                Reps
   2:
          4
                Input Gain = 1
   3:
         1
                SE Channel
   4:
        10
                No. of Cycles
   5:
          5
                Timeout (units = 0.01 seconds)
   6:
          1
                Loc [615period]
   7:
           .001 Mult
                                  ; convert microseconds to milliseconds
          0.0
                Offset
   8:
  Do (P86)
                                                    ; disable CS615
4:
   1:
        55
               Set Port 5 Low
```

¹ See Appendix A for information on how to minimise problems due to electromagnetic interference.

5: Polynomial (P55) ; convert period to water content 1: 1 Reps X Loc [615period] 2: 1 3: 2 F(X) Loc [615water] 4: -0.187 CO 5: 0.037 C1 6: 0.335 C2 0.0 7: C3 8: 0.0 C4 0.0 9: C5 6: Do (P86) Set Output Flag High 1: 10 7: Real Time (P77) 1: 0220 Day,Hour/Minute 8: Sample (P70) 1: 2 Reps 2: 1 Loc [615period] 9: End (P95) *Table2 Program 02: 0.0 Execution Interval (seconds) *Table3 Subroutines End Program

9.2 Simple Program Using the Pulse Count Instruction (P3) of a Datalogger to Read a Single CS615¹

The CS615 is measured when Flag 1 is set high. The measurement is made and the period and water content values are written to Final Storage.

Datalogger	CS615
Pulse Count Channel 1 (P1)	green
Control Port 5 (C5)	orange

The red lead is connected to 12V DC and the black lead and shield are connected to ground (G on CR10/10X and \perp on 21X and CR23X).

For the CR500/510 datalogger, use the connections specified by Short Cut.

```
* Table 1 Program01: 1.0 Execution Interval (seconds)
```

¹ See Appendix A for information on how to minimise electromagnetic interference.

1: If Flag/Port (P91) ; set flag 1 high to initiate reading Do if Flag 1 is High 1: 11 2: 30 Then Do ; enable CS615 2: Do (P86) 45 Set Port 5 High 1: delay for complete count interval; 3: Beginning of Loop (P87) 1: 1 Delay 2: 2 Loop Count 4: End (P95) 5: Pulse (P3) ;determine CS615 output frequency 1: 1 Reps 2: 1 Pulse Input Channel 3: 21 Low Level AC, Output Hz 4: 1 Loc [615kHz] .001 Mult 5: ;convert to kHz 0.0 Offset 6: ; disable CS615 6: Do (P86) 1: Set Port 5 Low 55 7: Z=1/X (P42) convert to milliseconds 1: 1 X Loc [615kHz] 2: 2 Z Loc [615msec] 8: Polynomial (P55) convert period to water content 1: 1 Reps 2: 2 X Loc [615msec] 3: 3 F(X) Loc [615water] -0.187 CO 4: 0.037 Cl 5: 0.335 C2 6: 7: 0.0 C3 8: 0.0 C4 9: 0.0 C5 9: Do (P86) 1: 10 Set Output Flag High 10: Real Time (P77) 1: 0220 Day,Hour/Minute 11: Sample (P70) 1: 2 Reps 2: 2 Loc [615msec] 12: Do (P86) 1: 21 Set Output Flag Low 13: End (P95) End Program

9.3 Program Using the Pulse Count Instruction (P3) of a 21X Datalogger and an AM416 Multiplexer to Read 48 CS615 Probes¹

	As advised above, the Period Measurement Instruction (Instruction 27) should always be used if possible, because of it is capable of giving much better resolution. However, this instruction is not available on the 21X (or CR7) datalogger, and this program is written to show how the Pulse Count Instruction (Instruction P3) can be used.			
	The program is written to read 48 CS value to Final Storage. The AM416 m four lines per channel. The output fro for all three probes, are attached to earenabled simultaneously while the Pul of three to sequentially read the probe Count Instruction is converted to periodibration to volumetric water content values.	615s every hour and write the water content nultiplexer is a 16-channel multiplexer with m three CS615s, plus a common enable line ch AM416 channel. Three CS615s are se Count Instruction uses a repetition value e outputs. The frequency value of the Pulse od by the $Z=1/X$ Instruction (P42) and the nt is invoked using the Polynomial are written to Final Storage.		
CAUTION	In some cases, when probes are and enabled simultaneously, t between them. See Appendix A for information o due to electromagnetic interference	within 200mm of each other here can be interference n how to minimise problems e.		
	To ensure accurate results you must g structure when using the Pulse Instru- enabled. See the detailed description The program assumes 12V DC power See Figure 2 for the wiring configura	tive careful consideration to the program to with sensors that are periodically of the Pulse Count Instruction in Section 6. is supplied to the AM416 and the CS615s. tion.		
CAUTION	Reading 48 CS615s using the I take approximately 32 seconds. measurements.	Pulse Count Instruction will This may conflict with other		
	 * Table 1 Program 01: 1.0 Execution In 	terval (seconds)		
	1: If time is (P92) 1: 0 Minutes into 2: 60 Minute Inter 3: 30 Then Do	a val		
	2: Do (P86) 1: 41 Set Port 1 H	;enable AM416		
	3: Do (P86) 1: 43 Set Port 3 H	;set CS615 enable line high		

¹ See Appendix A for information on how to minimise problems due to electromagnetic interference.

4:	Beg	ginning	of Loop (P87)	;Multiplexing loop	
	1:	0	Delay		
	2:	16	Loop Count		
;the are	ere is adva	a loop in nced thre	dex of 3 so that the three r ee locations with each pass	eadings measured by pulse instruction through the measurement loop	
5:	Ste	ep Loop	Index (P90)		
	1:	3	Step		
6:	Do	(P86)		;clock multiplexer	
	1:	72	Pulse Port 2		

; delay loop to wait remainder of execution interval in which multiplexer is clocked, and one complete execution interval for precise pulse count interval.

7:	Beginning of Loop (P87)					
	1:	1	Delay			
	2:	2	Loop Count			
8:	End	(P95)		;end of delay loop		
9:	Pulse (P3)			; read 615s		
	1:	3	Reps			
	2:	1	Pulse Input Channel			
	3:	21	Low Level AC, Output Hz			
	4:	1	Loc [kHz#1]			
	5:	.001	Mult			
	6:	0.0	Offset			

; convert frequencies to period. 0.001 multiplier on pulse instruction will give period in milliseconds.

10:	Z=1/	X (P42)
	1:	1	X Loc [kHz#1]
	2:	4	Z Loc [Period#1]
11:	Z=1/	X (P42)
	1:	2	X Loc [kHz#2]
	2:	5	Z Loc [Period#2]
12:	Z=1/	X (P42)
	1:	3	X Loc [kHz#3]
	2:	6	Z Loc [Period#3]
13:	Poly	nomial	(P55) ;apply calibration
	1:	3	Reps
	2:	4	Xloc [period#1]
	3:	7	F(X) Loc [water1#]
	4:	187	C0
	5:	.037	C1
	6:	.335	C2
	7:	0.0	C3
	8:	0.0	C4
	9:	0.0	C5
14:	End	(P95)	

; set CS615 enable low 15: Do (P86) 1: 53 Set Port 3 Low ; set port 3 low 16: Do (P86) ; set AM416 reset low ; set port 1 low 1: 51 Set Port 1 Low 17: Do (P86) 1: 10 Set Output Flag High 18: Sample (P70) ;write 48 results to output 1: 48 Reps 2: 7 Loc [Water#1] 19: End (P95) End Program

9.4 Program Using the Period Averaging Instruction (P27) of a CR10/10X Datalogger and an AM416 Multiplexer to Read 48 CS615 Probes

This program is similar to the one above, but uses the preferred Period Averaging Instruction available on the CR10/10X, CR23X and CR500/510 dataloggers.

CAUTION	In s and bet See due	In some cases, when probes are within 200mm of each other and enabled simultaneously, there can be interference between them. See Appendix A for information on how to minimise problems due to electromagnetic interference.					
	*	01:	Table 1 1.0	Program Execution Interval (se	conds)		
					;Once an Hour, Read Probes		
	-			(=00)	· · ·		
	1:	TI	time is	(P92)			
		1:	0	Minutes into a			
		2:	60	Minute Interval			
		3:	30	Then Do			
	2:	Do	(P86)		:enable multiplexer		
		1:	41	Set Port 1 High			
	3:	Do	(P86)		; turn on port that enables 615s		
		1:	43	Set Port 3 High			
	4:	Bec	ainning (of Loop (P87)	Multiplexer loop		
		1:	0	Delay			
		2:	16	Loop Count			
	5:	Do	(P86)		clock multiplexer;		
		1:	72	Pulse Port 2	*		

;loop index multiplied by 3 so that 3 readings measured by pulse instruction are advanced 3 locations each pass through measurement loop.

Step Loop Index (P90) 6: 1: 3 Step 7: Period Average (SE) (P27) 1: 3 Reps 2: 4 Input Gain = 1 3: 1 SE Channel 10 No. of Cycles 4: Timeout (units = 0.01 seconds) 5: 5 6: 1--Loc [msec#1] 7: .001 Mult 8. 0.0 Offset 8: End (P95) 9: Do (P86) ;set ports enabling mux and probes low 51 Set Port 1 Low 1: 10: Do (P86) 53 Set Port 3 Low 1: 11: Polynomial (P55) ; apply calibration 1: 48 Reps 4 2: X Loc [Period#1] 3: 49 F(X) Loc [WatCont#1] -0.187 CO 4: 5: 0.037 C1 6: 0.335 C2 7: 0.0 C3 0.0 C4 8: 9: 0.0 C5 12: Do (P86) Set Output Flag High 1: 10 13: Real Time (P77) Hour/Minute 1: 10 14: Sample (P70) 1: 48 Reps 2: Loc [WatCont#1] 49 15: End (P95) End Program



Figure 3 Wiring Configuration for Multiplexing 48 CS615s with AM416 and Various Dataloggers

Note that the CR500/510 dataloggers are usually programmed using Short Cut, which will indicate appropriate wiring connections.

Appendix A. Electromagnetic Interference — Avoiding Problems

The principle of operation of the CS505 is that it forms a high frequency oscillator, where the sensing rods are part of the oscillator circuit. A consequence of this is that it can act like a small radio frequency transmitter, where the rods form the transmitting antenna.

This Appendix lists the potential problems with respect to electromagnetic interference, and ways to minimise the effects of this interference.

A.1 Introduction

Depending on the exact type of installation and the method of operation of the CS615, the radio emissions from the sensor can exceed the EU limits for the generation of interference as defined in the Standard BS EN55022.

The emissions are at a very low level – at the worst case less than 1/300th of the output of a cellular phone – but have the potential to cause interference to other measurement equipment, and also nearby radio and television reception equipment.

The sensors should be operated following the general guidelines below to minimise the risk of interference to both your own, and other, measurement systems.

A.2 Minimising General Interference

To avoid generalised interference, you should take the following steps:

- a) Only power the sensor when actually taking measurements never power up the sensor continuously, especially when the rods are not in soil.
- b) If possible, use the Period Averaging Instruction (P27) with the CS615, as this allows you to take a measurement in only a few tens of milliseconds.
- c) Do not take measurements from the probe more frequently than required. For example, in most experiments, a measurement every few minutes, or even every hour or so, is adequate, due to the slow rate of change of moisture content.
- d) Avoid operating the probe near to other equipment, and preferably at least 200m away from domestic residences.
- e) Avoid installing the probe with the rods close to other metal objects; e.g. grounding rods, earth wires, etc. A separation of at least 300mm is recommended.

A.3 Minimising Problems within a Measurement System

To avoid problems in a specific measurement system:

- a) Do not install the probes very close to other types of sensor, especially if you will be powering up the CS615 at the same time as you will be taking readings from the other sensor.
- b) If several CS615 probes are installed close together, they should either be enabled and measured individually, or they should be physically separated by at least 300mm. This separation is required as adjacent probes have sometimes been found to lock on to each other and resonate at a common, erroneous, frequency.
- c) The CS615 itself can also be affected by the effects of strong radio interference. Usually this will result in an increase in the frequency output giving unrealistically low, or even negative, water content readings. To avoid these problems, do not install or operate the probe near to strong sources of radio frequency emissions, for example cellphones or RF transceivers.