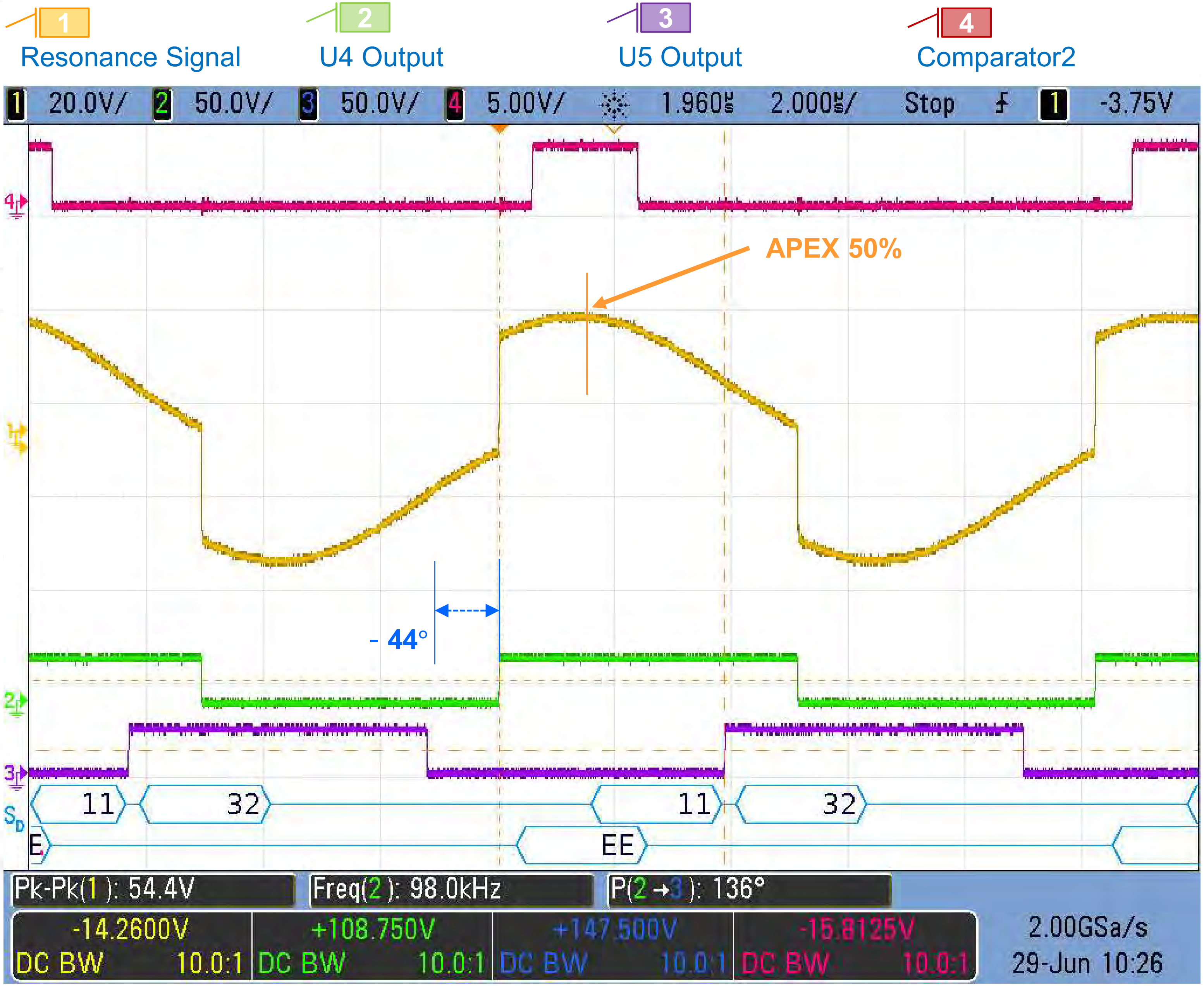
X11. Thrust Control 44° Phase Shift / 50% Thrust Output



When the load becomes larger, the phase shift is reduced and the thrust output is increased.

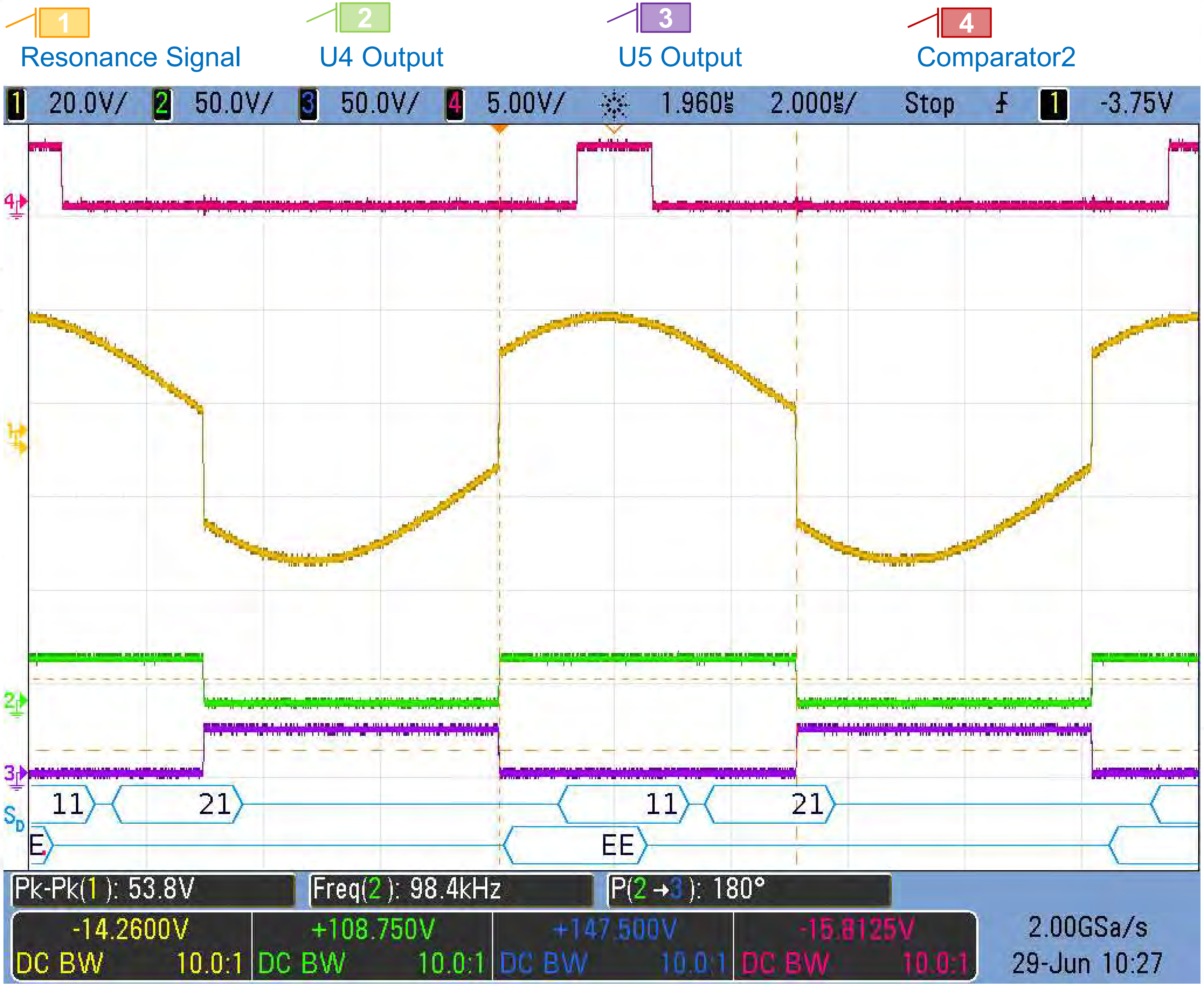
Adjustment method is:
When more than 50% thrust is used → reduce the phase shift and increase the thrust → the thrust usage will decrease

When the thrust is used less than 50% → the phase shift increases and the thrust decreaases→ the thrust usage will increase

This is a quick adjustment method for thrust control. It is mainly used to quickly change the load and its corresponding small range output power regulation in a short time.

A wide range of power adjustment still needs to be controlled through the frequency conversion system

X12. Thrust Control 0° Phase Shift / 33% Thrust Output



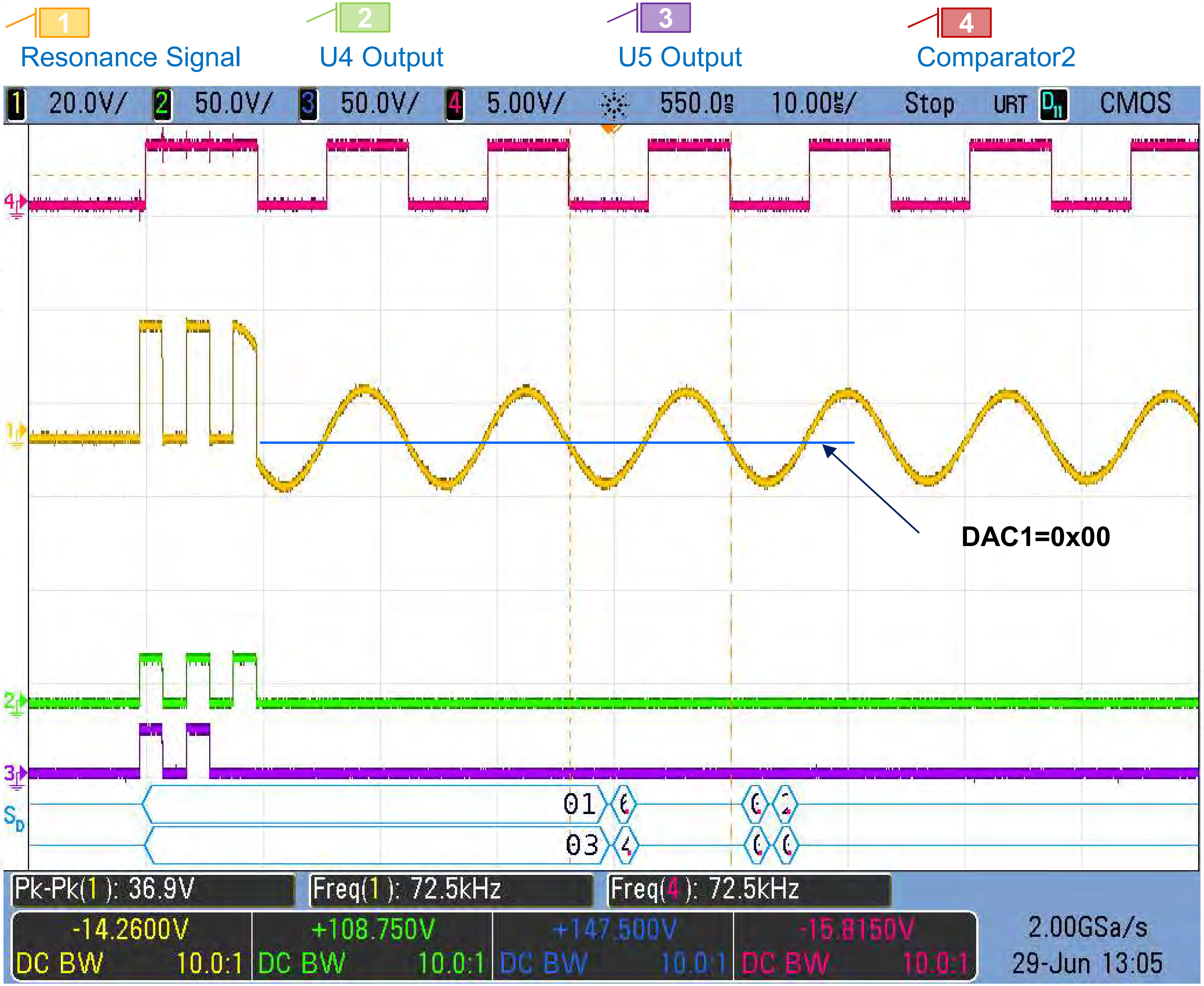
Thrust control can be used to adjust power output with low frequency range at low power

However, in the high power section, more thrust is needed to cope with load changes in a short time.

Therefore, it will monitor the power supply current. If the current is greater than the set value, the full thrust output will be maintained.

The current preset configuration: maintain full thrust output when the input current of the TX terminal is greater than the maximum limit of 1/8.

X13. Resonant Frequency Scanning Detection without RX Link

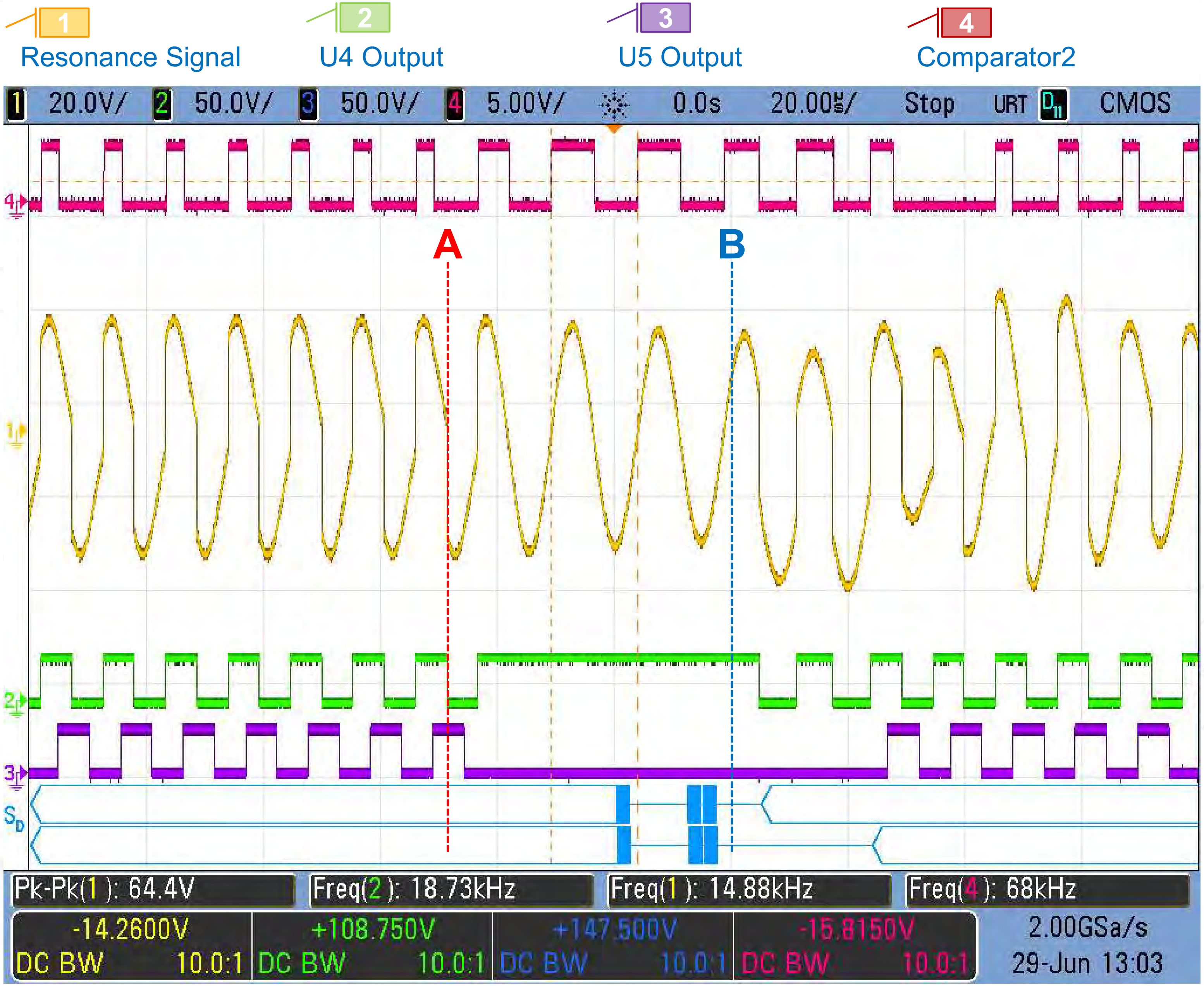


When there is no RX end connection, there is only the resonant frequency on the TX detection coil
Make the coil self-oscillate state after the PWM is driven briefly.

Input the coil signal to comparator 1
Reference voltage DAC1 is set to 0

The resonant signal on the coil will pass through the voltage zero volts. The transition occurs at the output of the comparator.

X14. Resonant Frequency Measurement during Power Transmission



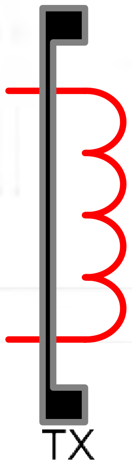
Resonant frequency measurement in power transmission is more complicated

Stop PWM drive at time point A

Measurement stage starts from time point A to time point B

Re-engagement phase at point B

X15. LC resonant frequency

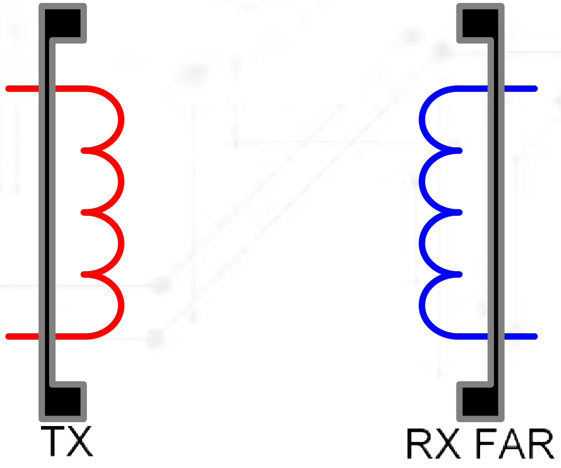


The wireless power transmission coil TX COIL and the matching capacitor on the circuit board have the characteristics of the resonant frequency. The resonant frequency here refers to the frequency of the internal voltage damping oscillation of the LC combination. In the wireless power system, the capacitance on the circuit board is mostly NP0 (C0G) MLCC. Its capacitance is less than the temperature change, so the main factor affecting the LC resonance frequency is the inductance on the coil.

The change in inductance on the coil is mainly affected by the surrounding materials. In short, if the magnetic material which does not absorb electromagnetic power is equipped, the inductance can be increased. If a metal body that absorbs electromagnetic power is equipped, the inductance will be reduced.

The magnetic material will change the inductance by the temperature change. At present, most of the magnetic materials used in the industry can maintain stable performance at 70 degrees.
Define a state firstly. ACCurate LC RESonant frequencythe means TX COIL has magnetic material on the non-inductive surface, and there is no object on the sensing surface.
This frequency will be checked during system startup mode.

X16. Define The Maximum Distance for TX COIL and RX COIL Where the Power can be Transmitted

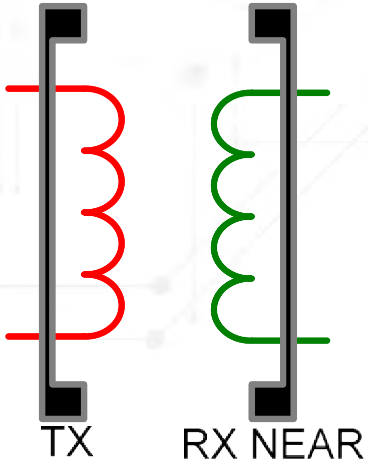


The wireless power transmission needs to receive the rated power at the RX end. The farther the distance between TX COIL and RX COIL is, the worse the efficiency will be. And the TX end will send more power to get the RX end to receive the rated power.

If the TX end sends too much power, the circuit will be damaged and cause safety problems. Therefore, it is necessary to limit the upper limit of the power transmitted by the TX terminal. Therefore, the RX wants to receive the rated power so that the distance between the TX COIL and the RX COIL is less than a range. Define FAR as the maximum working distance.

The inductance value on the TX COIL is affected by the magnetic materials behind the RX COIL.
The closer the two coils are, the greater the inductance on the TX COIL is.
And the resonant frequency will decrease
Define the resonant frequency of the two coils at the maximum working distance as LC RES FAR

X17. Define The Shortest Distance for TX COIL and RX COIL Where the Power can be Transmitted

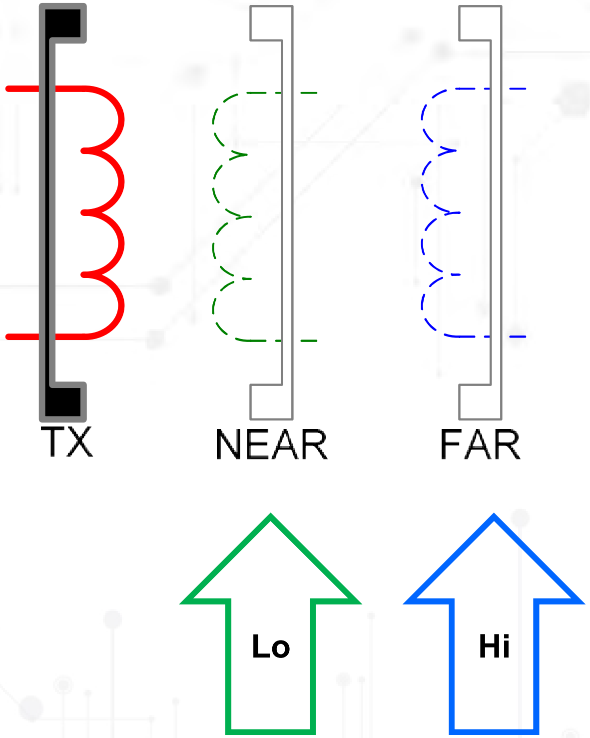


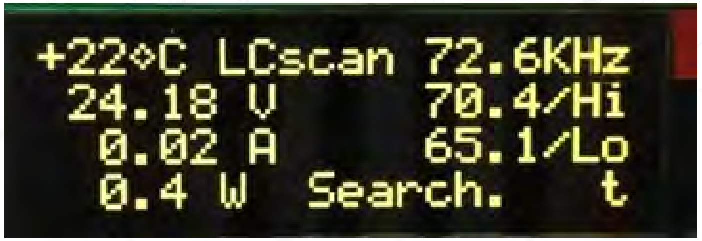
When the distance between TX COIL and RX COIL is shorter, the efficiency is higher. However, if the distance is too close, the power on the TX end will be nearly fully sensed on the RX end. When the coil distance is too close and there is no load, the RX end will receive too much power, so that the voltage of the rear part of the rectifier will be too high. Technically, TX will adjust the power output, but the minimum power output will also have its limit. Therefore, it is necessary to define the shortest distance between RX COIL and TX COIL under the minimum power output of TX.

The TX COIL is affected by the magnetic material behind it after the RX COIL is close, which will increase the inductance. When the distance between these two coils is shorter, the inductance will increase more. The more the inductance increases, the lower the resonant frequency will be. Therefore, the distance between TX COIL and RX COIL can be discriminated by the change of resonant frequency.

Define the resonant frequency of the two coils at the shortest working distance as LC RES NEAR

X18. Define the Working Distance Range of the Coils

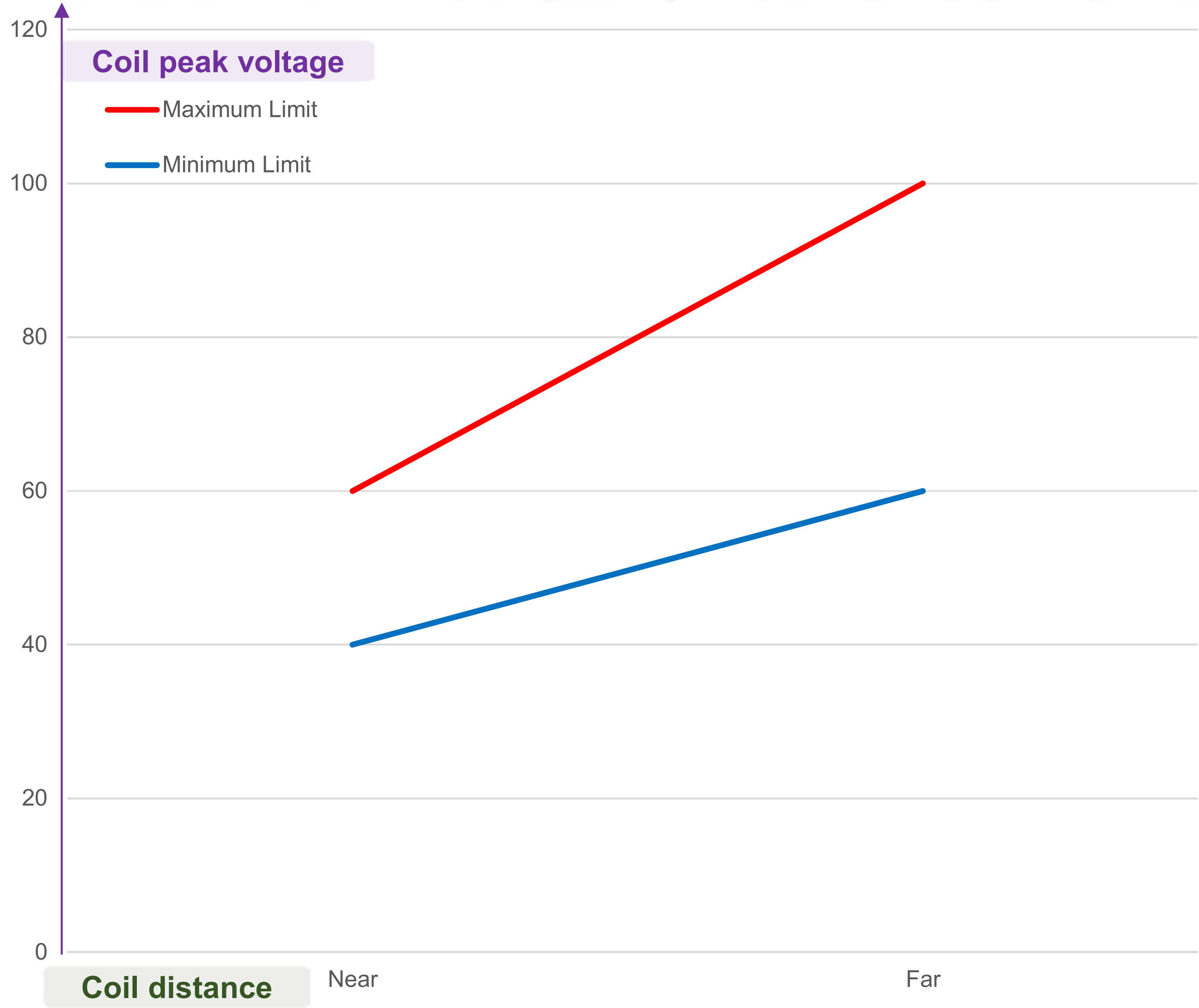




After the longest and shortest distances between TX COIL and RX COIL, the longest and closest distances can be set to Hi and Lo respectively, and the resonant frequency on TX COIL can be continuously measured when the TX end is at standby.
It is called LC sacn (LC resonant frequency scanning)
By continuously measuring the resonant frequency on the TX COIL, whether the measured value is between Hi and Lo can be observed. If the value is not within the range, it indicates that RX COIL is outside the range, the power transmission should not be performed.

During the power transmission, the resonance frequency change on the TX COIL is also continuously measured. When the resonance frequency is outside the range between Hi to Lo, it indicates that the RX COIL has deviated from the operable range. It is necessary to continue to cut off the power transmission.

X19. TX Coil Resonance Voltage Working Range



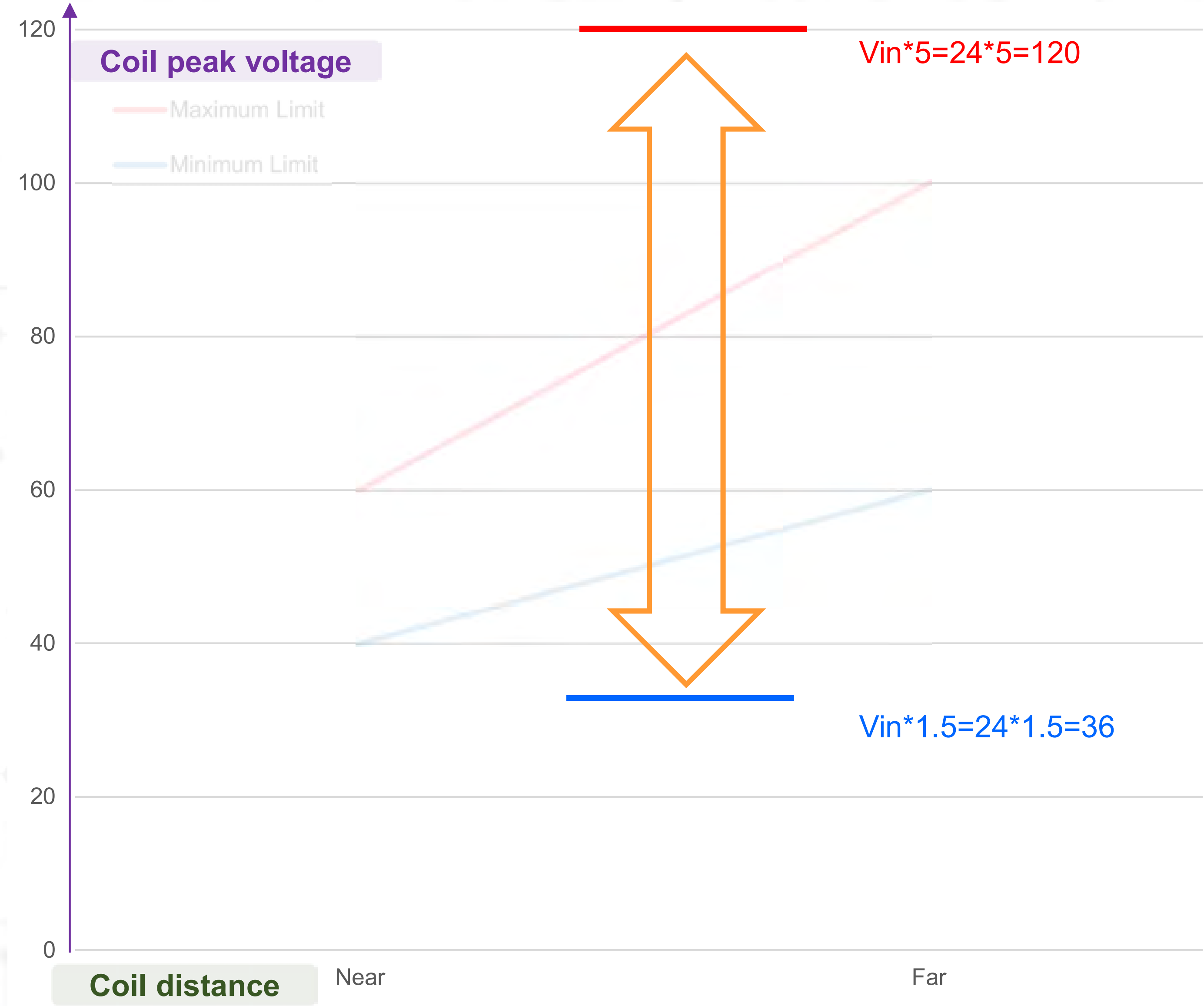
The transmmitted power of TX COIL is determined by the peak voltage at which the resonant voltage occurs. The higher the voltage, the greater the transmitted power.

When distance between coils is long, it needs to transmit a large amount of power to meet the RX power-receiving requirement. On the contrary, when the distance is short, the maximum value of the transmitted power will be limited to a low level, preventing the RX from receiving too much power and causing damage.

In practice, the power required to be transmitted by the TX COIL when the RX outputs the maximum power is defined as the Maximum Limit. When the RX output is unloaded, the power that the TX COIL needs to transmit is defined as the Minimum Limit.

The system will set the peak voltage on TX COIL between Max and Min according to the requirements of RX output.

X20. Working Range of Ideal Coil Resonance Voltage (Take the Operating Voltage of 24V DC as an example)



The resonant voltage is mainly formed by the driver pushing the LC oscillation. The closer the driving frequency is to the resonant frequency of the LC, the higher the resonant voltage will be.

Excessive resonant voltage can lead to poor efficiency and hardware damage. If the resonant voltage is too low, the RX will receive less power and the power supply will be interrupted.

After being driven, the coil needs to maintain the resonance reaction of the lowest limit. Otherwise, the RX cannot encode and modulate the data. The minimum limit should be greater than 1.5 times the operating voltage of the TX.

The definition of the maximum resonant voltage is determined by the performance of the coil. High-performance coils can maintain higher resonant voltages under the same transmission power for higher efficiency. In order to pursue system reliability, the resonant voltage is usually limited to the 5 times the TX operating voltage.

X21. Set Two Max and Min to Define the Working Range

Set two max and min

COIL V MAX FAR =130
Upper limit of the voltage, farthest to the coil

COIL V MAX NEAR =110
Upper limit of the voltage, nearest to the coil

COIL V MIN FAR =60
Lower limit of the voltage, farthest to the coil

COIL V MIN NEAR =33.9
Lower limit of the voltage, closest to the coil

The working range can be defined by these four points.

In fact, when operating, it will retreat to the green space in the figure than the limit value. And under the normal operation, the upper and lower limits will not be touched.

X22. Set the Upper and Lower Limits of the Voltage in the Setting Mode

Set the values from No. 26 to No. 29 in the setting mode

COIL V MAX FAR = 130
Upper limit of the voltage, farthest to the coil

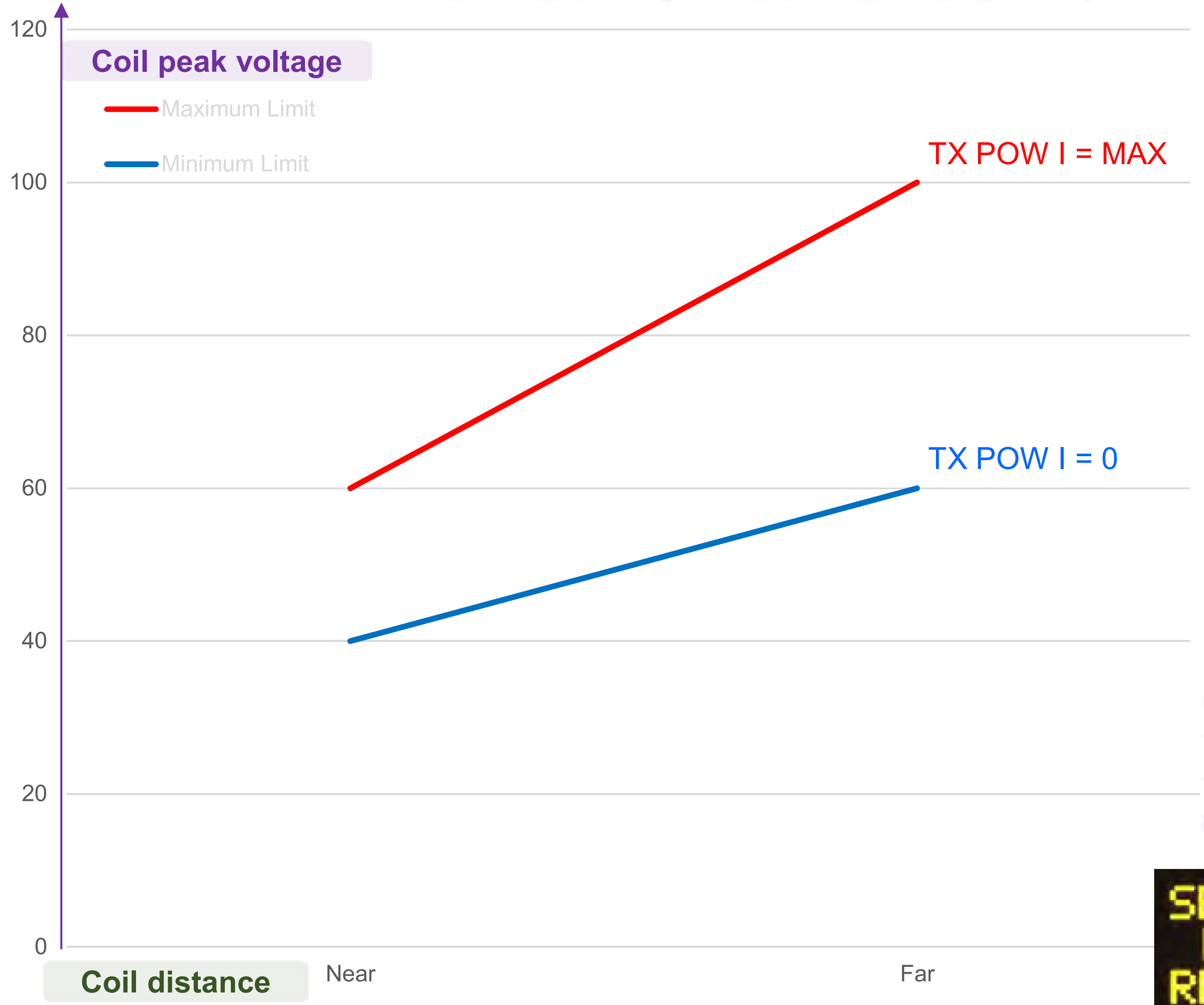
COIL V MAX NEAR = 110
Upper limit of the voltage, nearest to the coil

COIL V MIN FAR = 60
Lower limit of the voltage, fathest to the coil

COIL V MIN NEAR = 33.9
Lower limit of the voltage, nearest to the coil

This set value is usually set after the maximum load output at the different positions of the observed coil and the peak value of the resonance voltage of the operation under no-load operation. It is also set according to the reference value of the preset margin space.

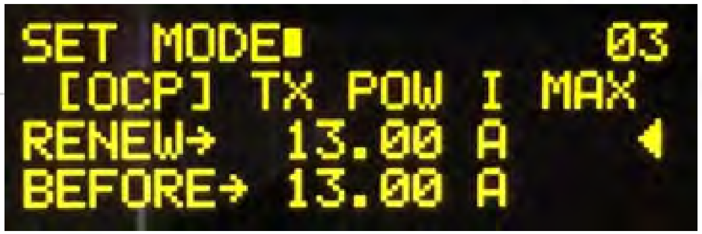
X23. Correlation Between Coil Resonance Voltage and Input Current



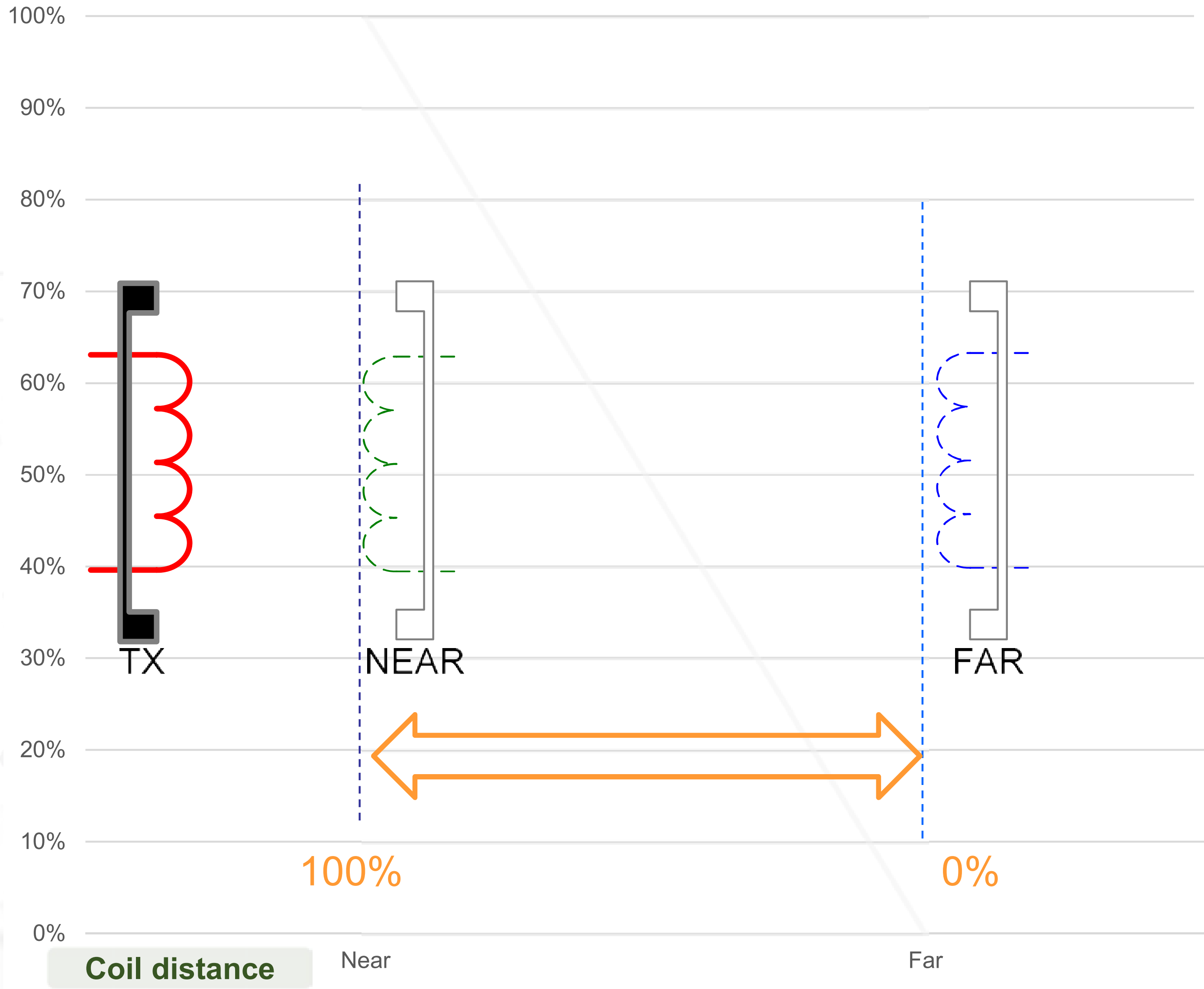
TX POW I is defined as the input DC current value of the TX terminal. When the RX terminal output power is higher, the current input to the TX terminal will also increaseS.

When the TX COIL resonance voltage reaches the maximum value, it indicates that the state of the device is at the maximum current output, whereas the coil resonance voltage at the minimum value indicates the no-load.

The description here refers to the situation after changing the vertical spacing of the coils under the condition that the coils are aligned at the center.



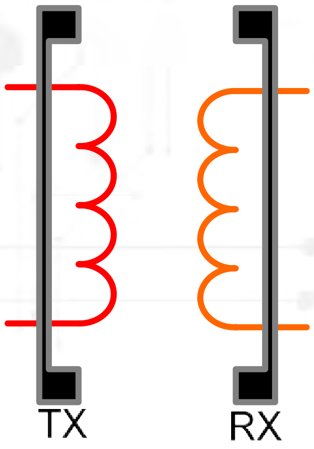
X24. Numerical Index of Distance Between Coils

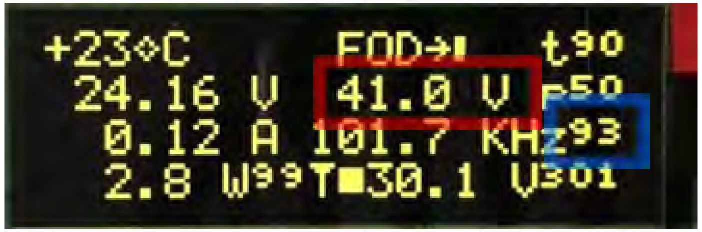


If the position of the coil is within the working range, the position can be calculated. In order to facilitate the calculation, the nearest distance is defined as 100%, and the farthest distance is defined as 0.

For convenience of explanation, the coil in the figure is enlarged and marked with the farthest distance and the closest distance. In fact, when the coil diameter is 4cm, the actual distance between 100% and 0% is only about 5mm.

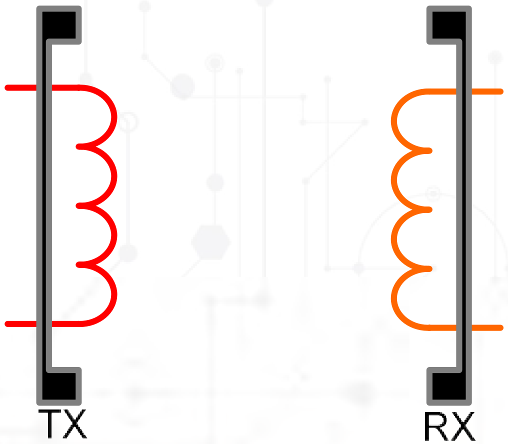
X25. Correlation Between Coil Vertical Distance and Resonant Voltage





The coil distance is displayed on the OLED. The number 99% means the nearest distance and 0 means the farthest distance.

The coil detection distance is 93%. When the two coils are close to each other, the coil resonance voltage can satisfy the RX power-receiving requirements as long as the peak-to-peak value of 41.0V is reached.



The coil detection distance is 4%. When the two coils are far apart, the coil resonance voltage must reach 71.3V to meet the RX power-receiving demand.

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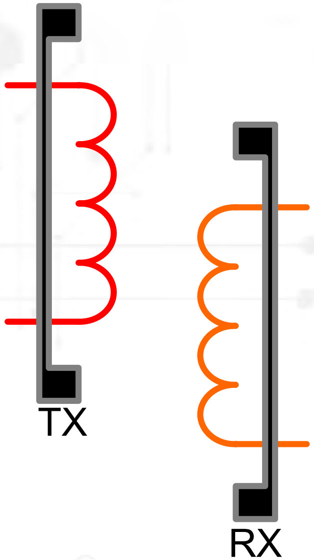
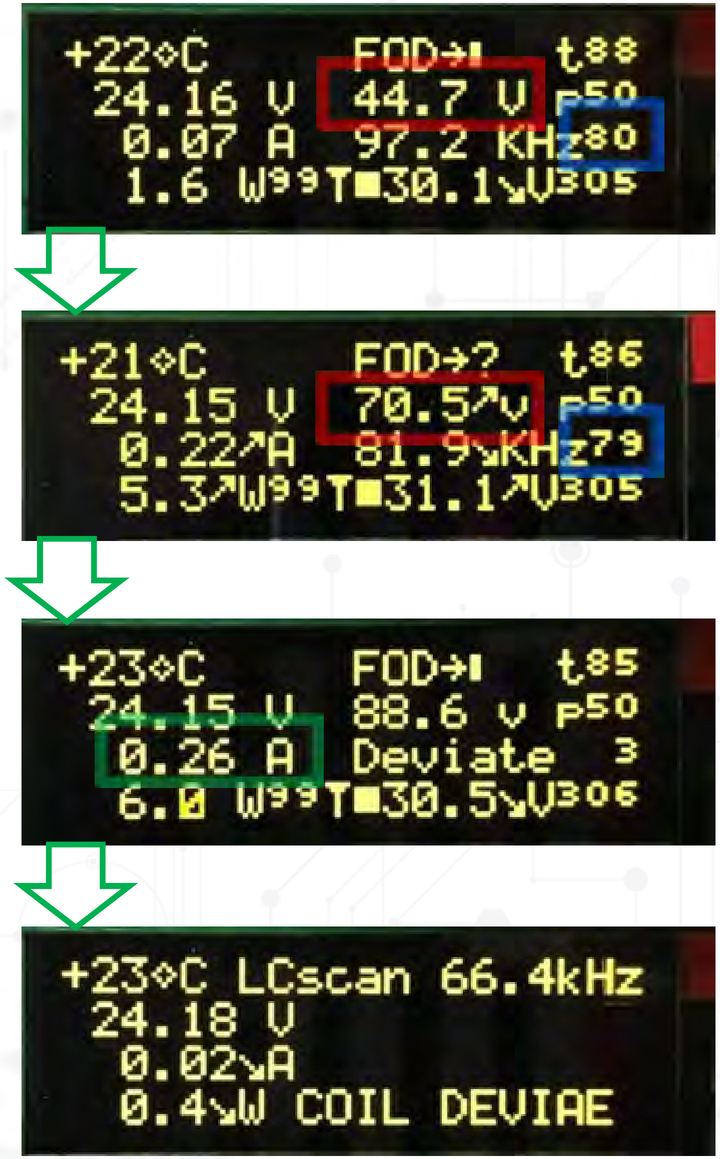
X26. Correlation Between Coil`s Horizontal Shift and Resonant Voltage





In the case of center alignment, the distance measurement is 80%,44.7V of the coil resonance voltage can meet the RX output requirements.

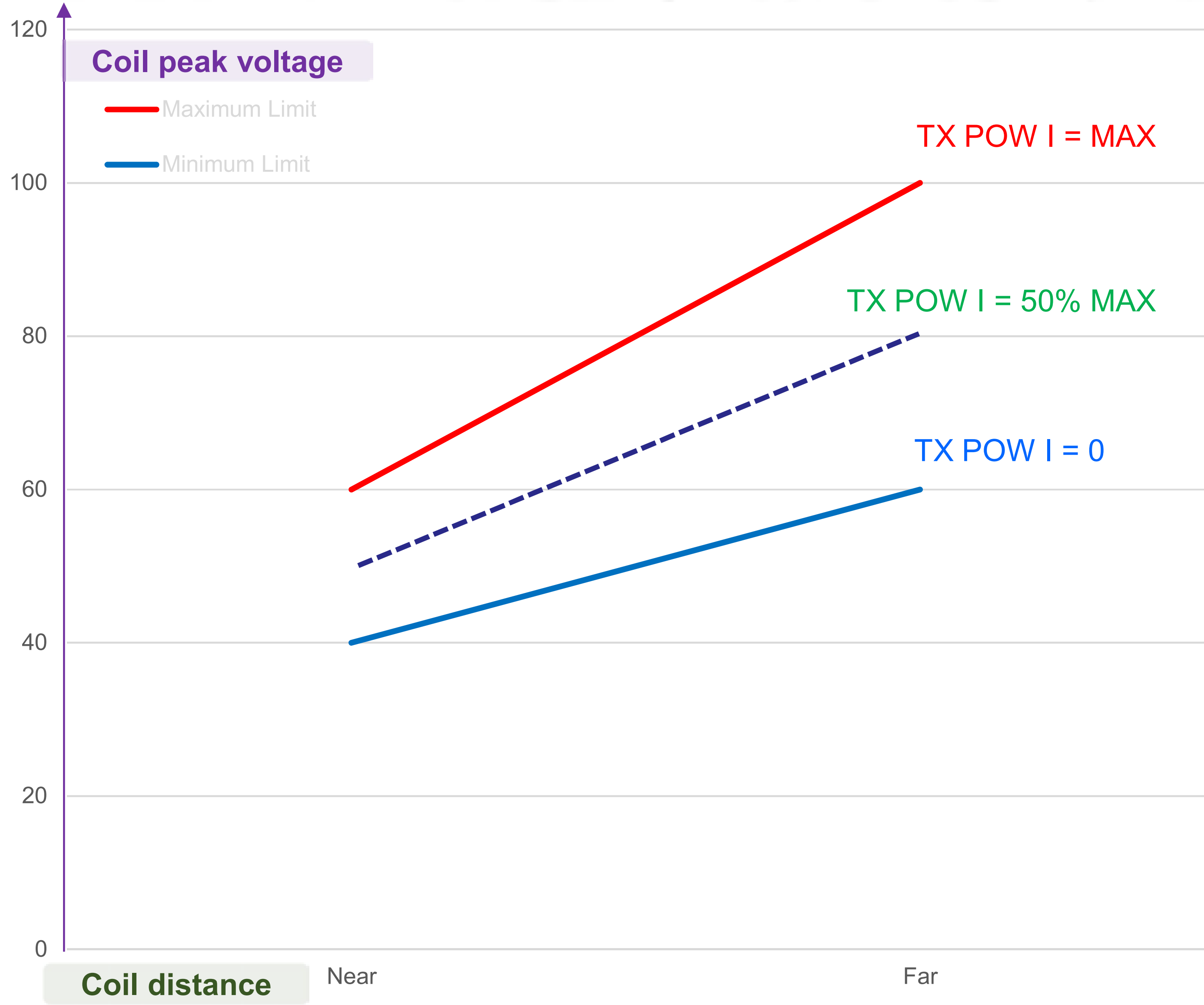
The coil is horizontally shifted because the magnetic material behind the RX COIL is still close to the TX COIL, so the measurement distance is 79%. The state is close to the center alignment. Because the distance is long, the resonant voltage must be increased to 70.5V to meet the RX power-receiving requirements.

The system will calculate the resonance voltage after it is increased. In normal cases, the power of the RX output should be increased, and the TX current value should be increased.

However, in fact, the current increases a little, so it is judged that the coil is deviated.

After the coil is deviated, the system will lock and not output power until the coil is repositioned. Then it will restart.

X27. Estimate Coil Resonance`s Voltage Range by Input Current and Coil Distance



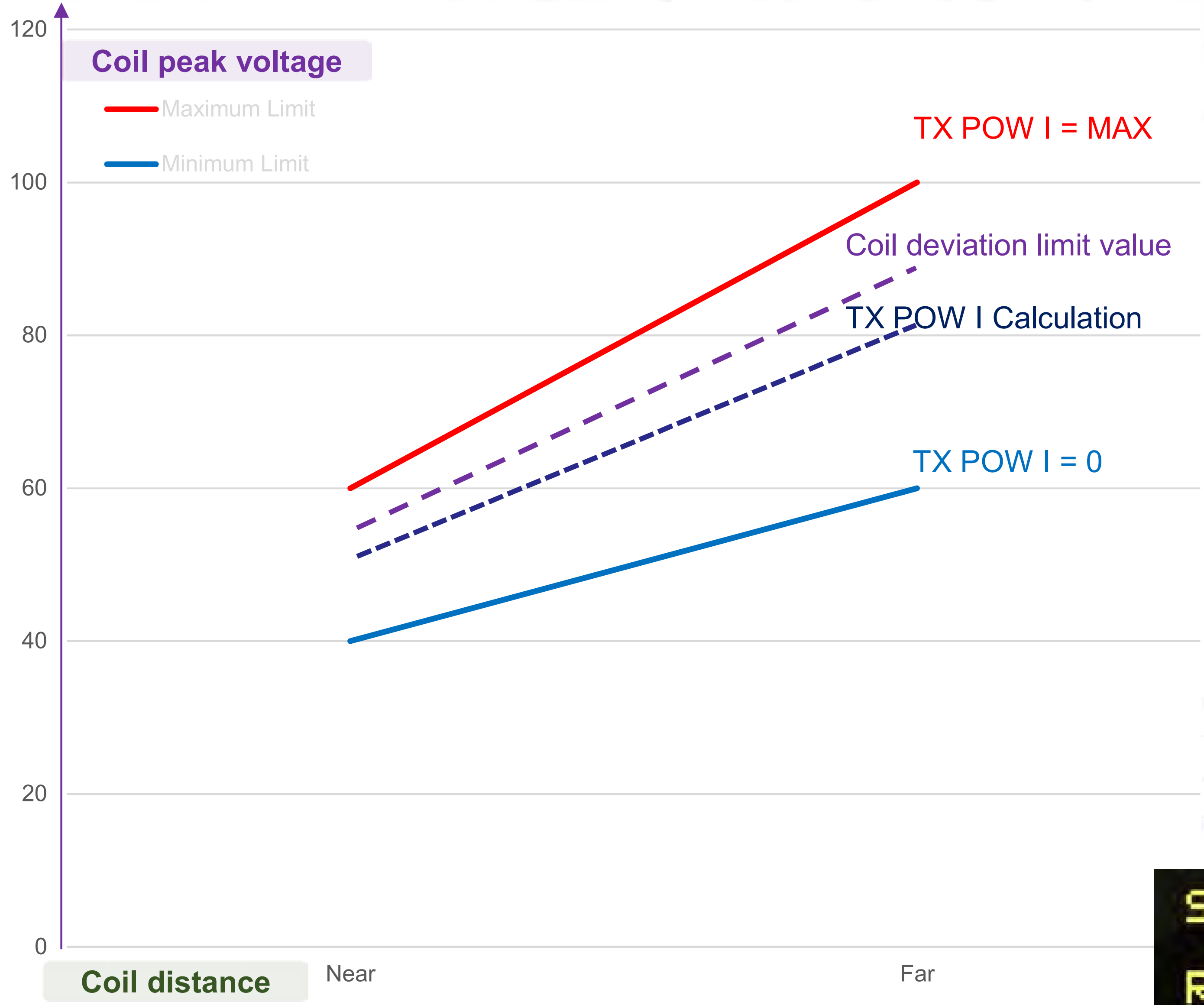
When the input current is at its maximum value, the resonant voltage is at its maximum value.

When the input current is 0, the resonant voltage is at the minimumlevel.

Therefore, it is estimated that when the input current is half of the maximum value, the coil resonance voltage will be in the middle of the maximum and minimum values.

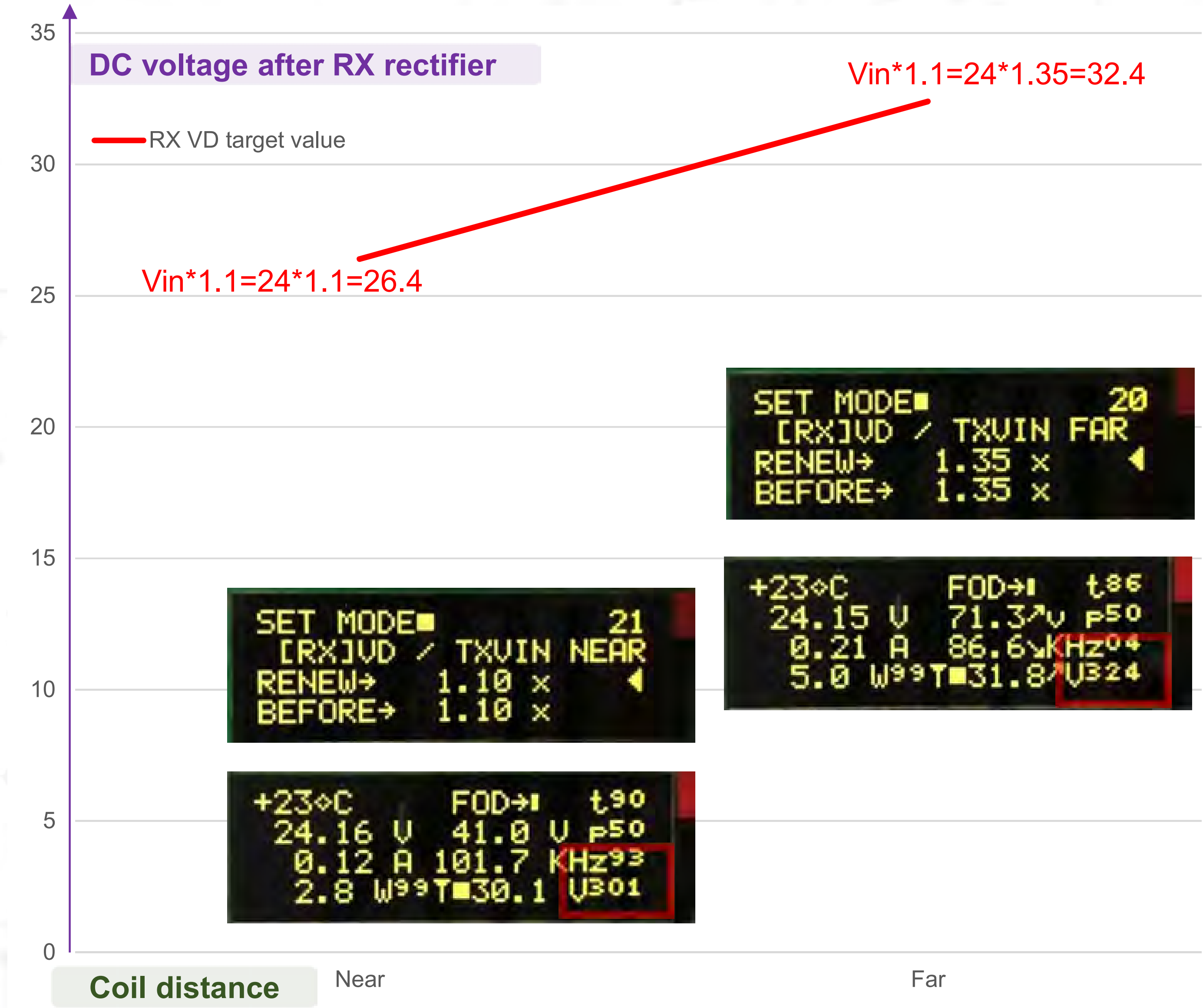
Based on this principle, the working range of the TX COIL resonant voltage can be estimated by measuring the distance of the coil and the condition of the input current.

X28. Calculate the Resonance Voltage Limit Value for Determining the Coil`s Shift



By the distance between the coils and the input current
In addition, a tolerance amount is set. The unit here is the current value. The calculation method is the measured current value plus the tolerance amount <COIL Dev Basis >, and the upper limit of the working range of the resonance voltage can be calculated. If the measured resonance voltage is higher than this value, it is determined that the coil horizontal shift is too obvious.

X29. Set DC Voltage Adjustment Target Value after RX rectifier



The TX end meets the output demand of the RX end through the power adjustment. The set value of the voltage before the rectifier and the voltage regulator at the RX end has a great influence on the performance. The voltage at the point is too high and the efficiency is thus lowered. Conversely, if the output is too low, the output will be insufficient when the load is increased in a short time

When the distance between coils is long, the current driving capability of the coil is poor. It is necessary to set the RX rectifier to have a higher DC voltage (defined as VD) to cope with sudden changes in load. When the distance between coils is short, the adjustment target will be reduced. Because the coil current driving force is large in this case, it can be coped with a lower VD, and the efficiency will be higher.

The setting mode of VD is a multiple of the TX input voltage, and the reasonable setting value is 1.1X~1.5X.

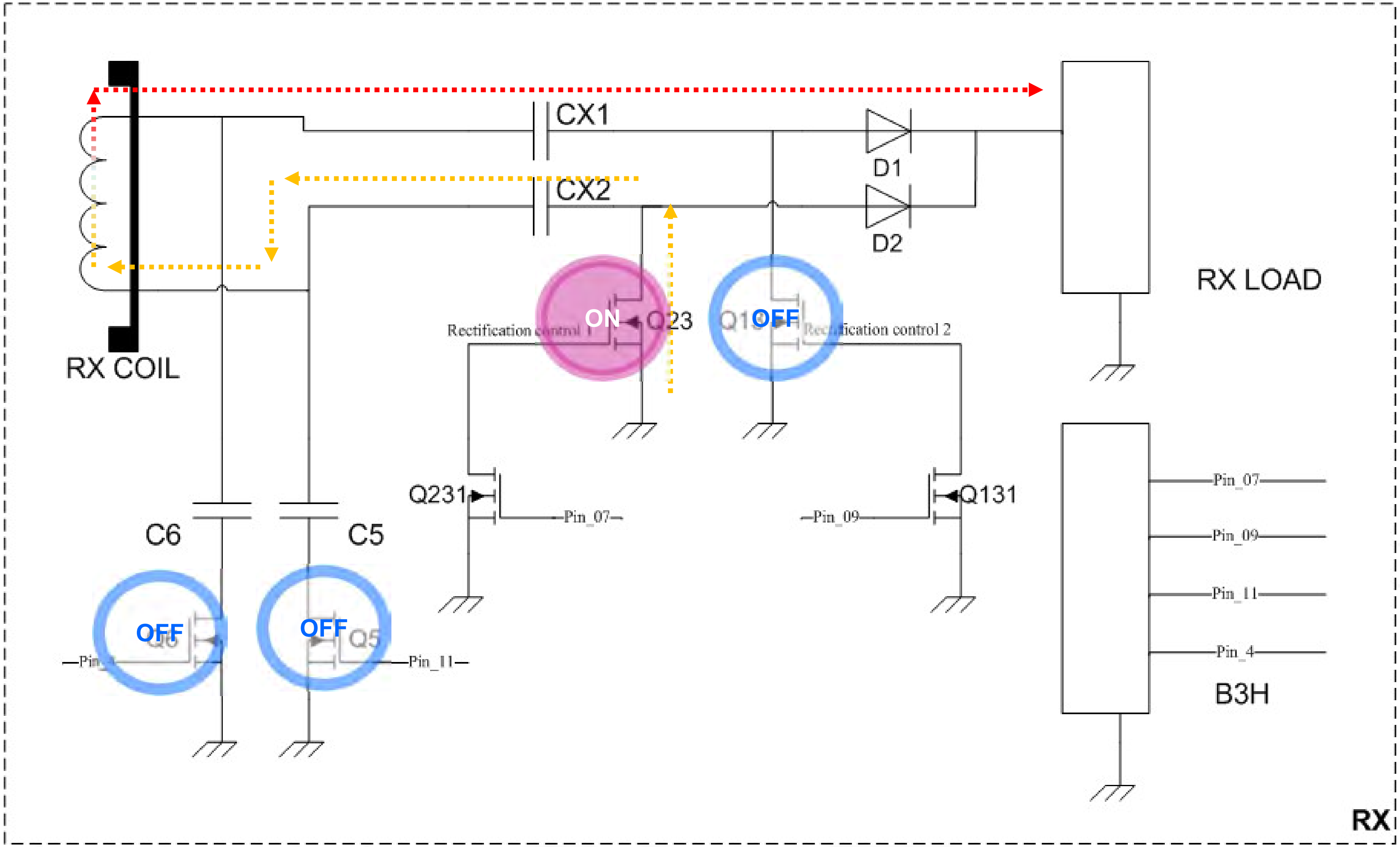
The higher the magnification, the worse the efficiency.

Setting the VD voltage to less than TX`s VIN to make voltage work unstably.

Y01.Communicate on the Power Transmitting Coil

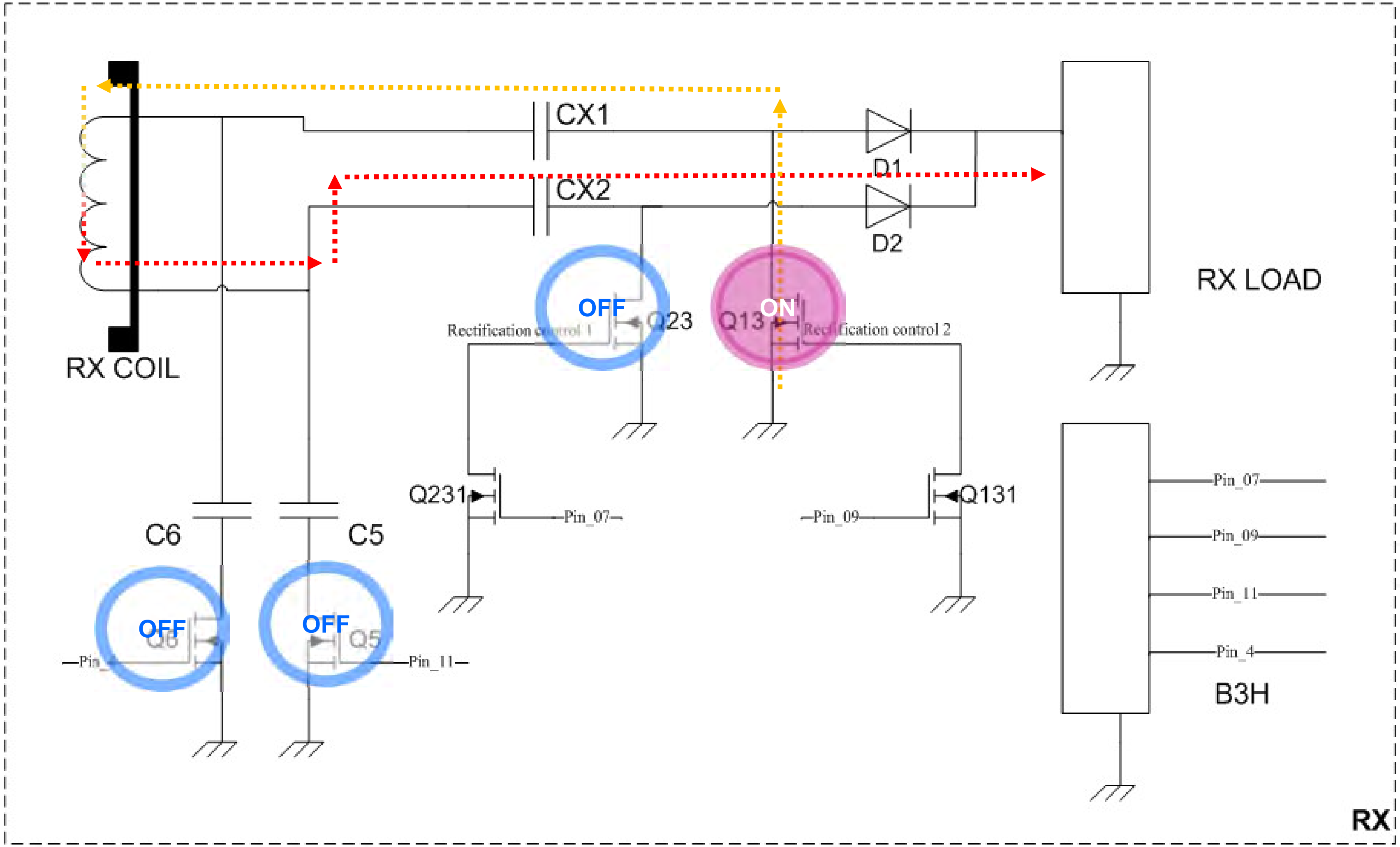
Adjustment Method	Advantages	Disadvantages
A. In-Band / ASK Similar to UART encoding	Currently the most widely used WPC (qi) communication method	Only suitable for low power Slow data transmission rate, Low ability to cope with noise and dynamic load interference
B. In-Band / Jitter Timing interval encoding	It is suitable for medium power Strong anti-noise ability and strong resistance to dynamic load interference	Slow data transmission rate
C. Out-of-Band / BLE …	Communication is not associated with power transmission. It is unaffected by load, high data transmission rate, it can be transmitted in both directions	Have extra parts, cost is increased.

Y02.Rectifier action - positive half cycle

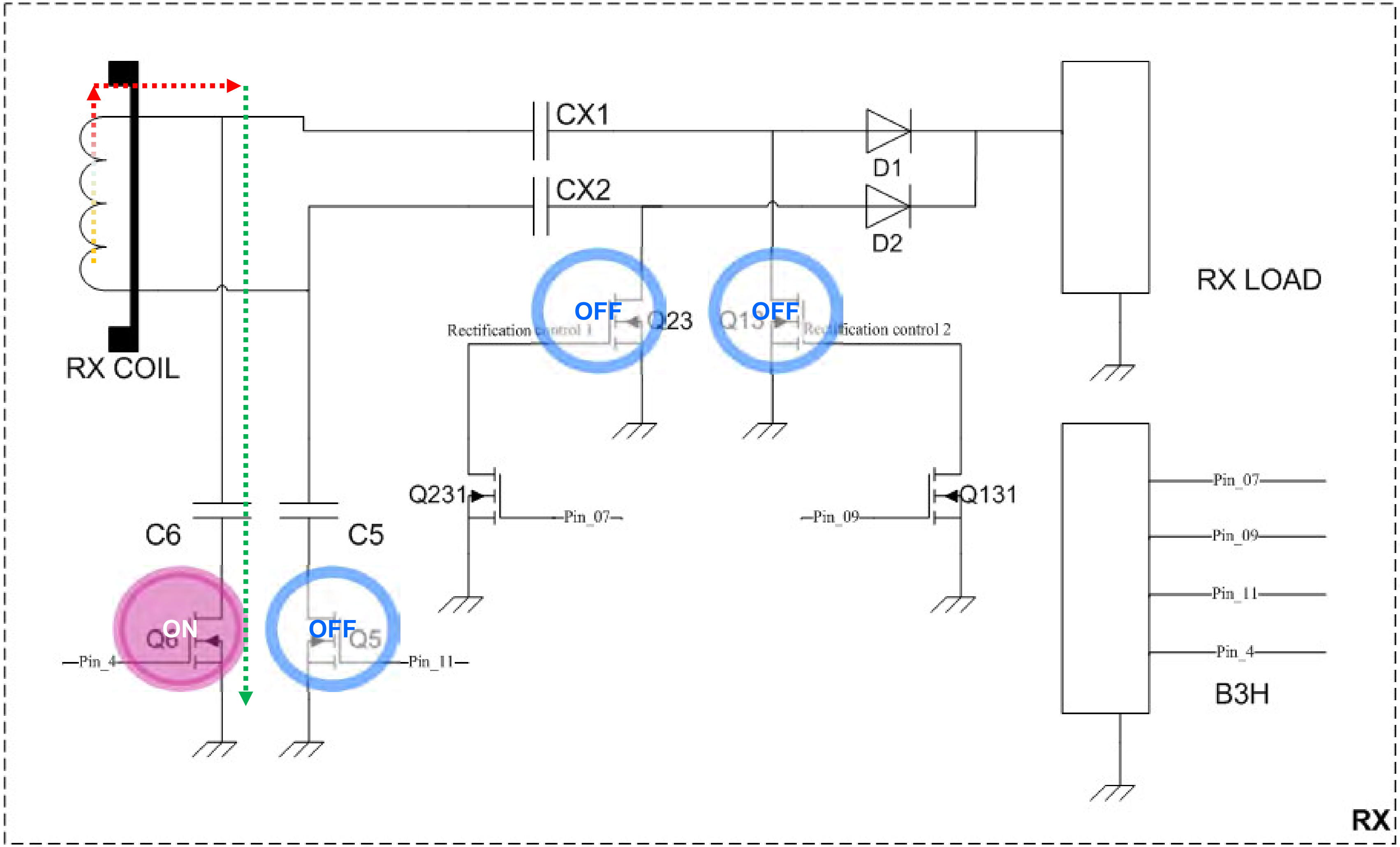


Current direction

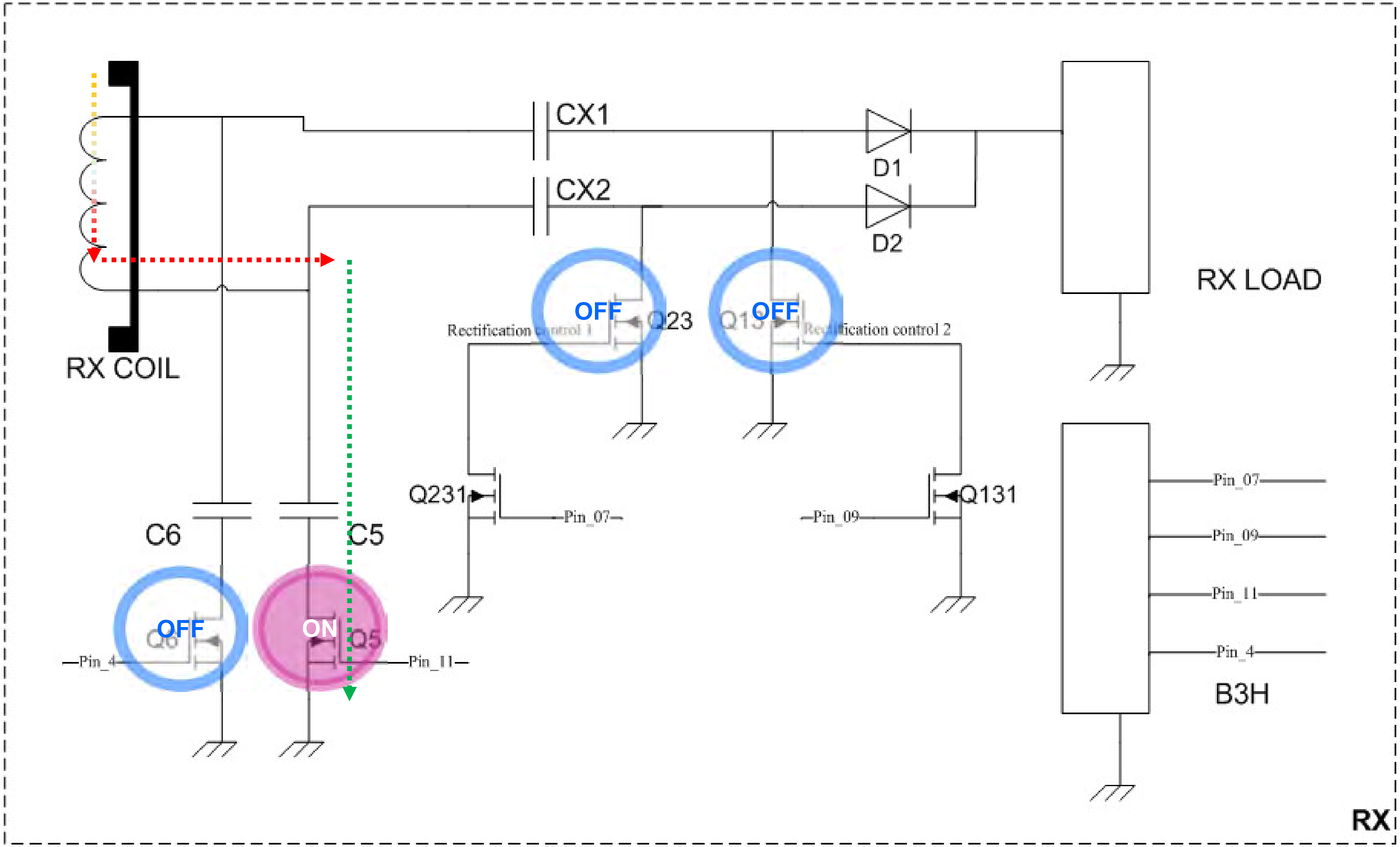
Y03. Rectifier action - negative half cycle



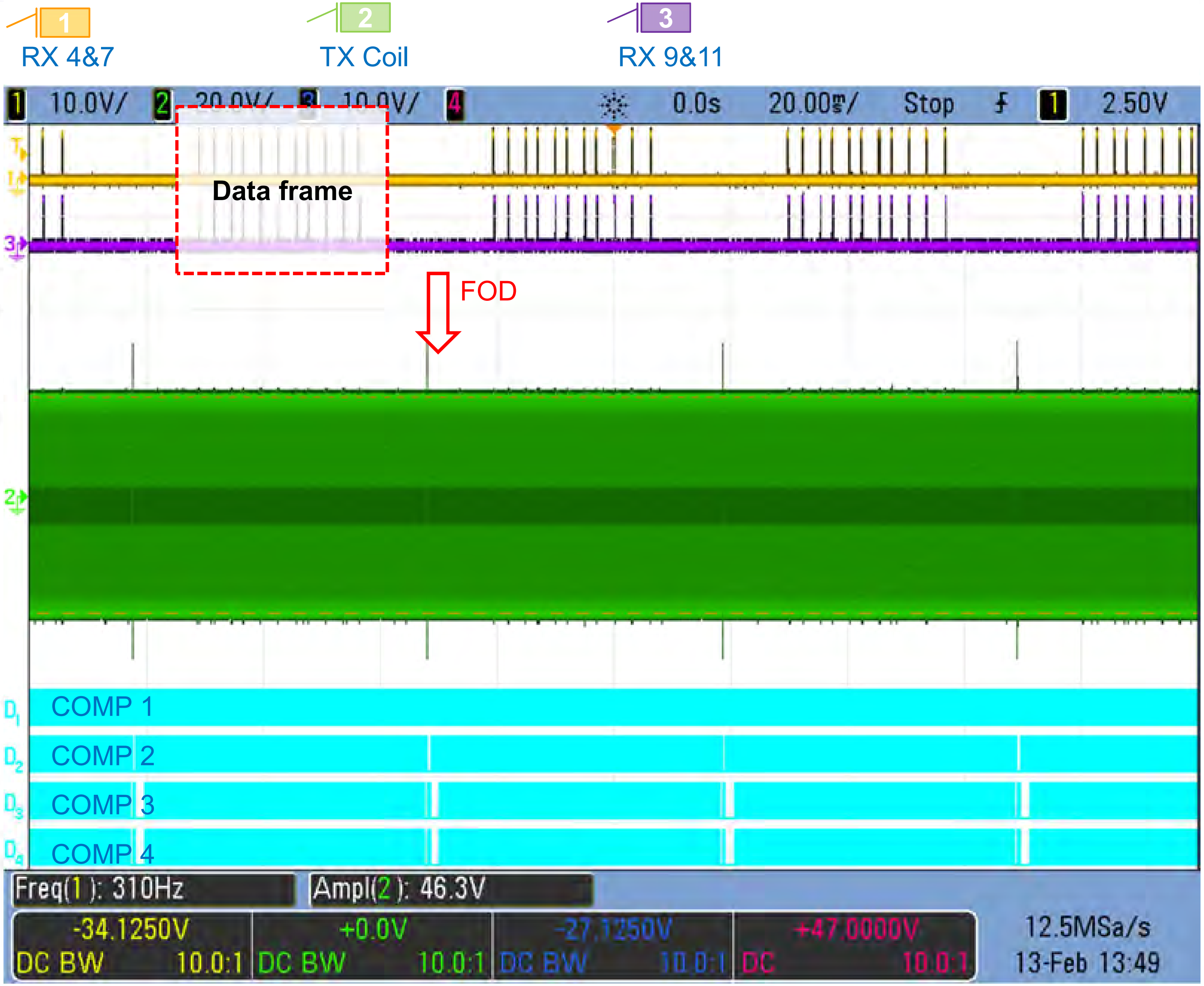
Y04. Modulating signal action - positive half cycle



Y05. Modulating signal action - negative half cycle



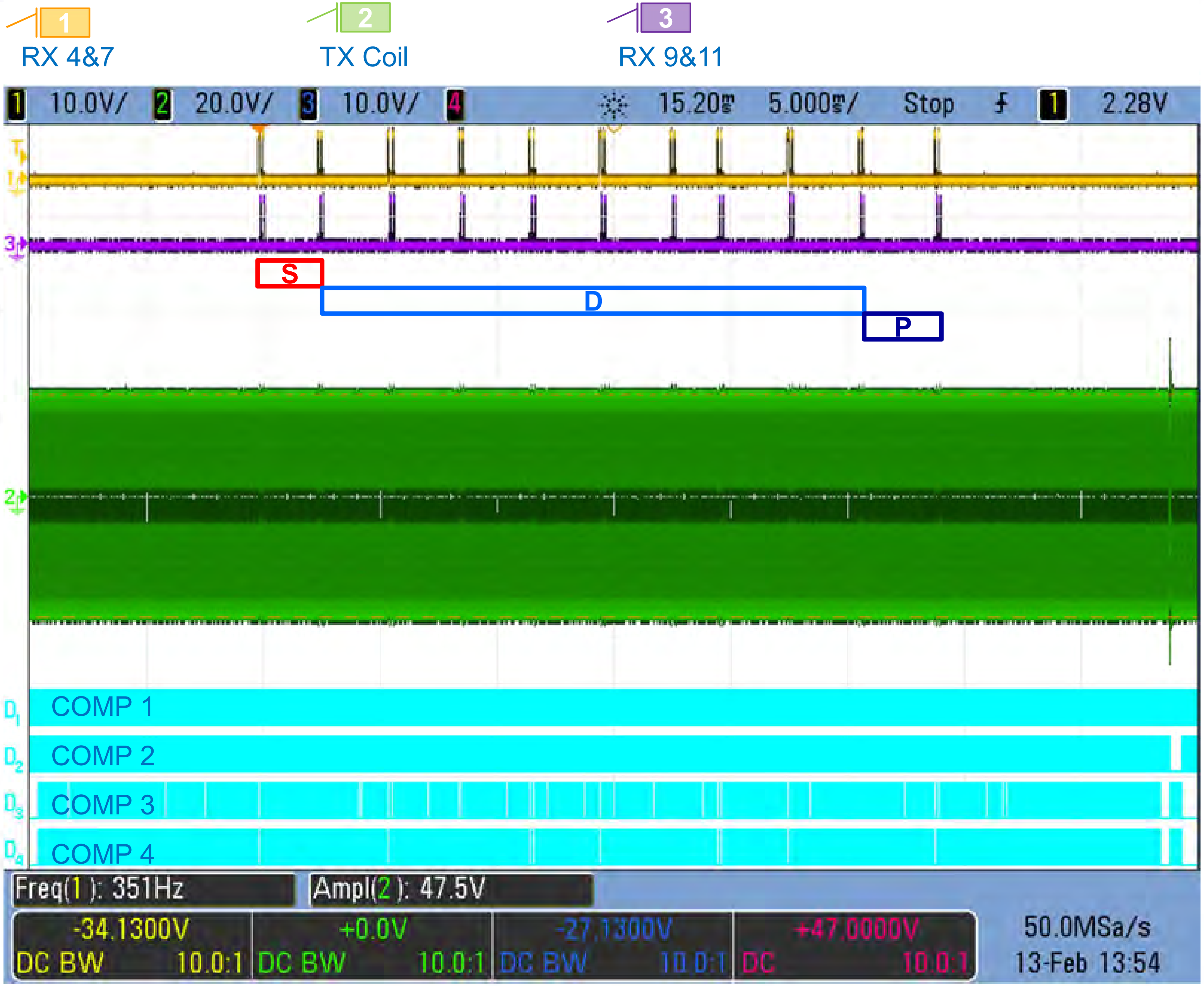
Y06. RX modulation/TX demodulation



In the power control loop, RX needs to constantly transmit the power status currently received to the TX end after coding the power status. After receiving the coded power status, the TX end will conduct power regulation according to the content. In this design, data is transmitted in the following way: TX transmits the power carrier signal, RX receives the signal and converts it into electric power to output to the load. In addition, ASK modulation is performed on this signal and the data code is arranged on it, then TX analyzes and decodes the signal.

In this design, 50 ms is used as a data cycle. Each data frame is made up of 11 jitter signals. An FOD detection mechanism is inserted in the middle of the data frame.

Y07. Data coding method



The content of data frame is:

Start Fixed time duration: 2.5ms

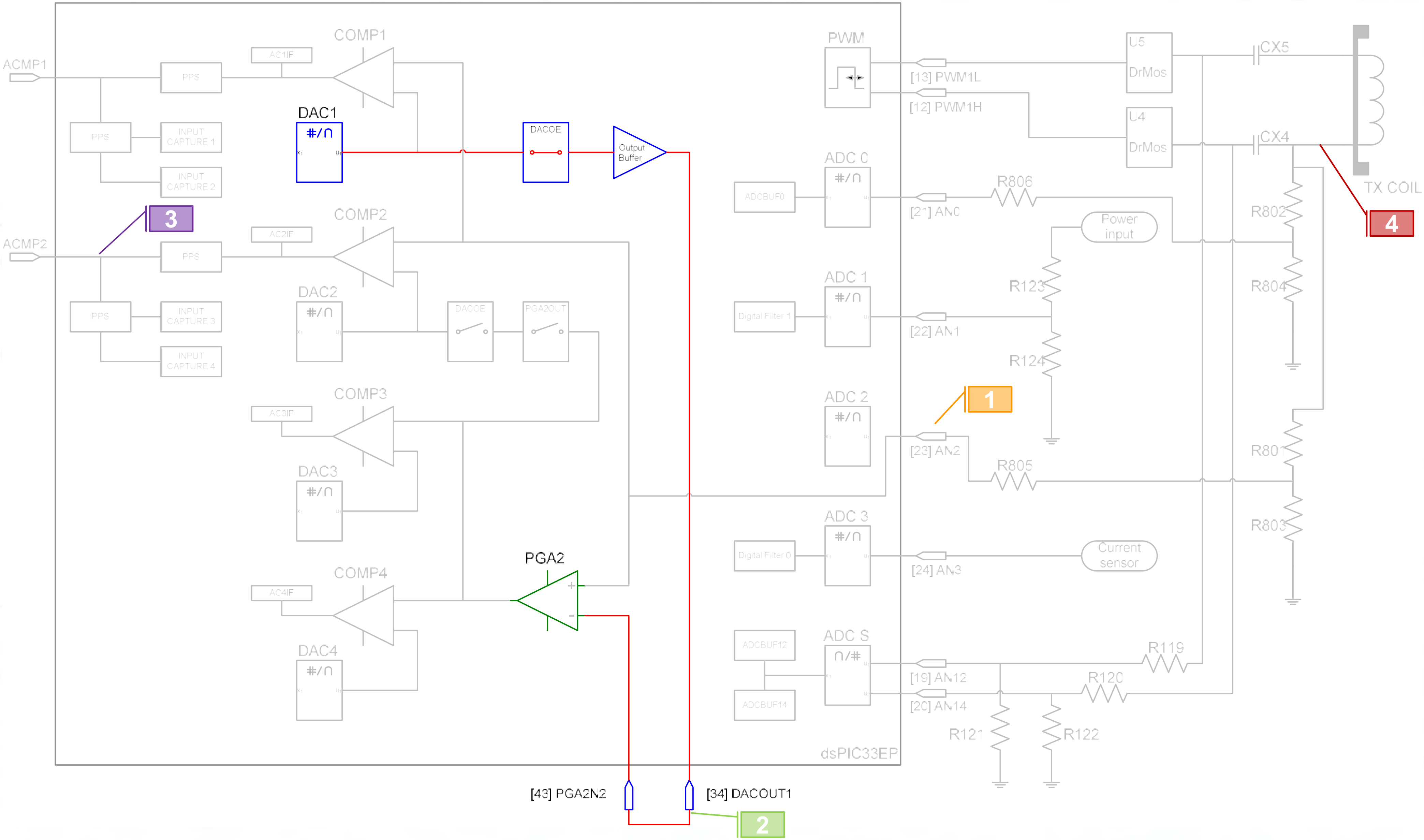
Data Bit0 = 2ms Bit1 = 3ms

Parity Bit0 = 2.75ms
Bit1 = 3.25ms

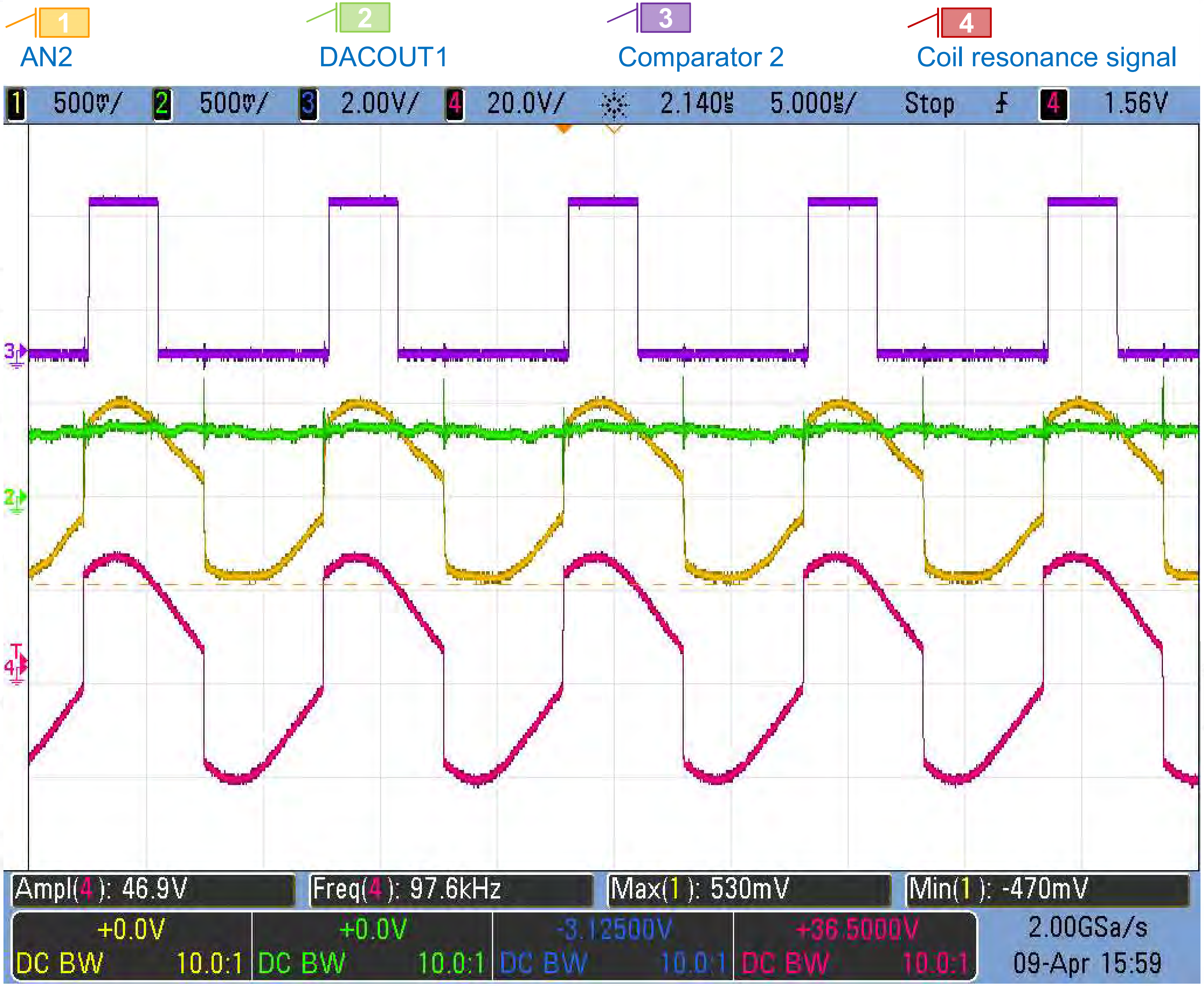
The time duration for the two jitter signals is the coding content. The TX decoding technology is mainly to analyze the time duration for decoding after the jitter characteristics are found out from the coil signal.

In the actual operation, the signal on the coil is very complex as it has much noise. When the power is increased, the RX end is very difficult to modulate out an obvious signal from the coil. This coding technology is an effective data transmission method specialized for high power environment. The data transmission speed is 20 bytes per second.

Y08. Configuration for voltage level at the negative input of PGA2

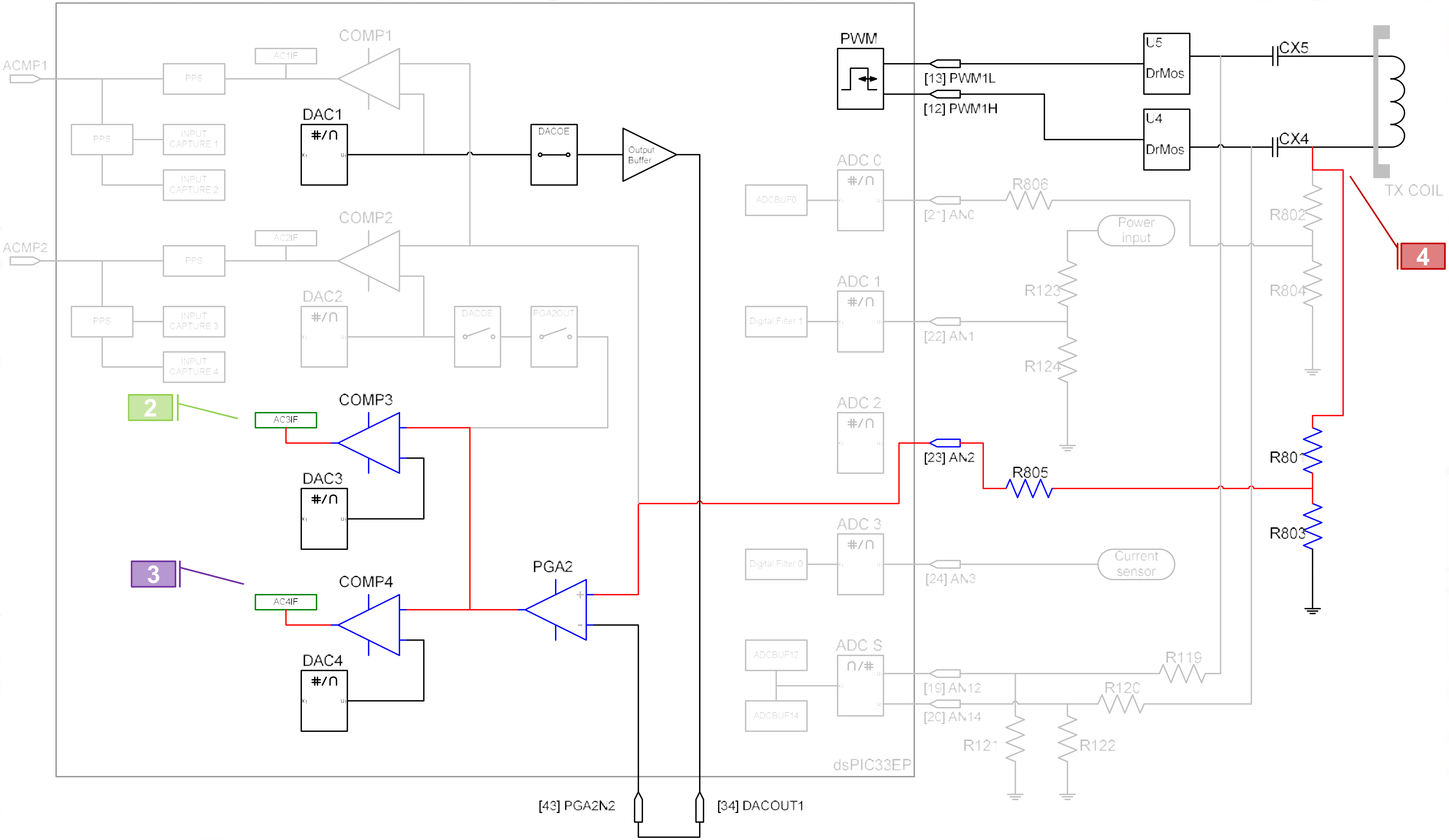


Y09. Configuration for voltage level at the negative input of PGA2

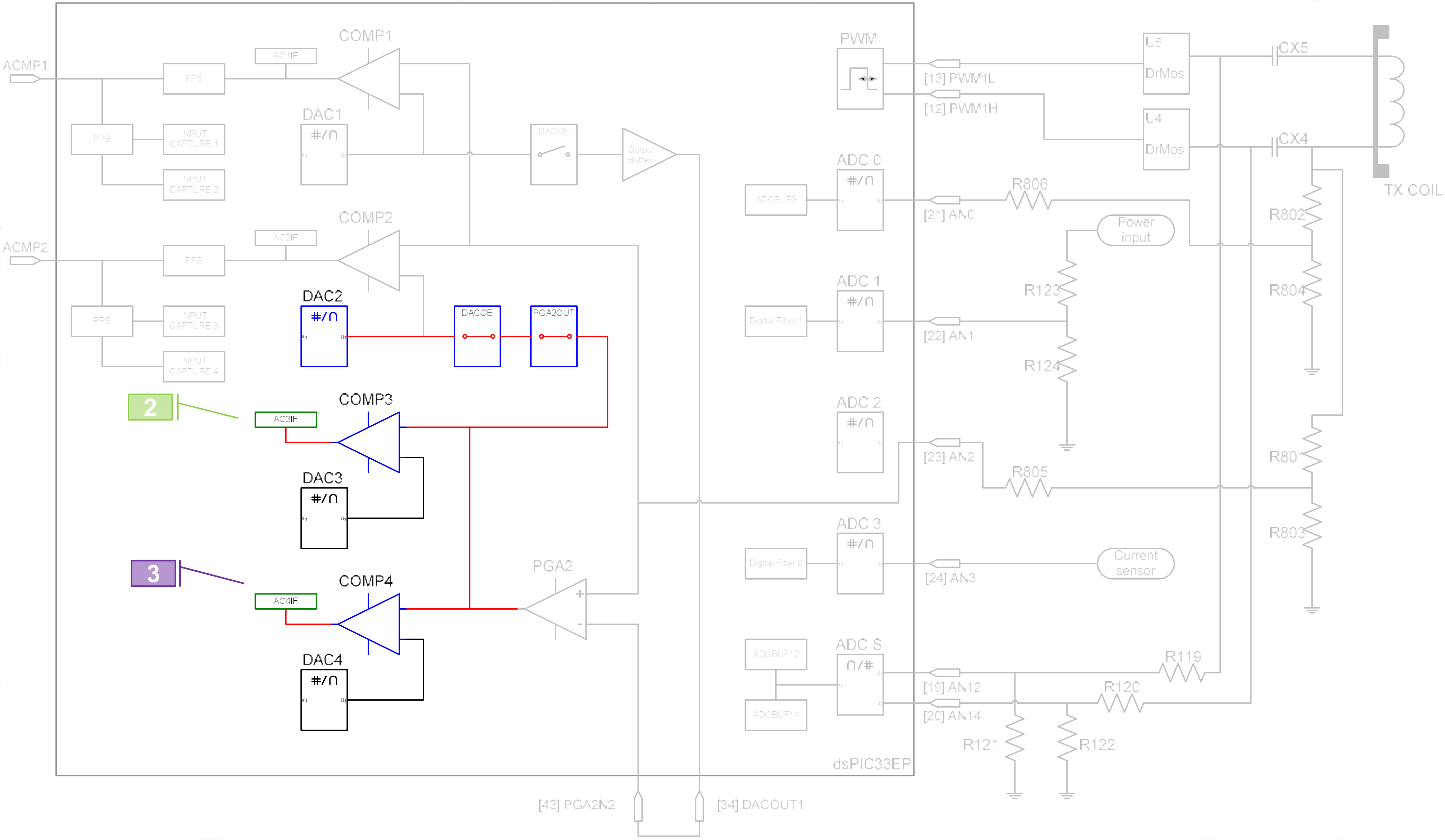


The way to decode the signal is to amplify a small section of the peak of coil resonance signal and then analyze it. The amplitude of the modulation signal needs to be amplified because it is too small to be accurately determined. PGA needs an adjustable voltage level, but in the IC, DAC cannot be directly connected to the input of PGA. So the voltage is output by DACOUT1 and then input to the input of PGA. The voltage level is set by DAC1 and then set by software according to the decoded signal level.

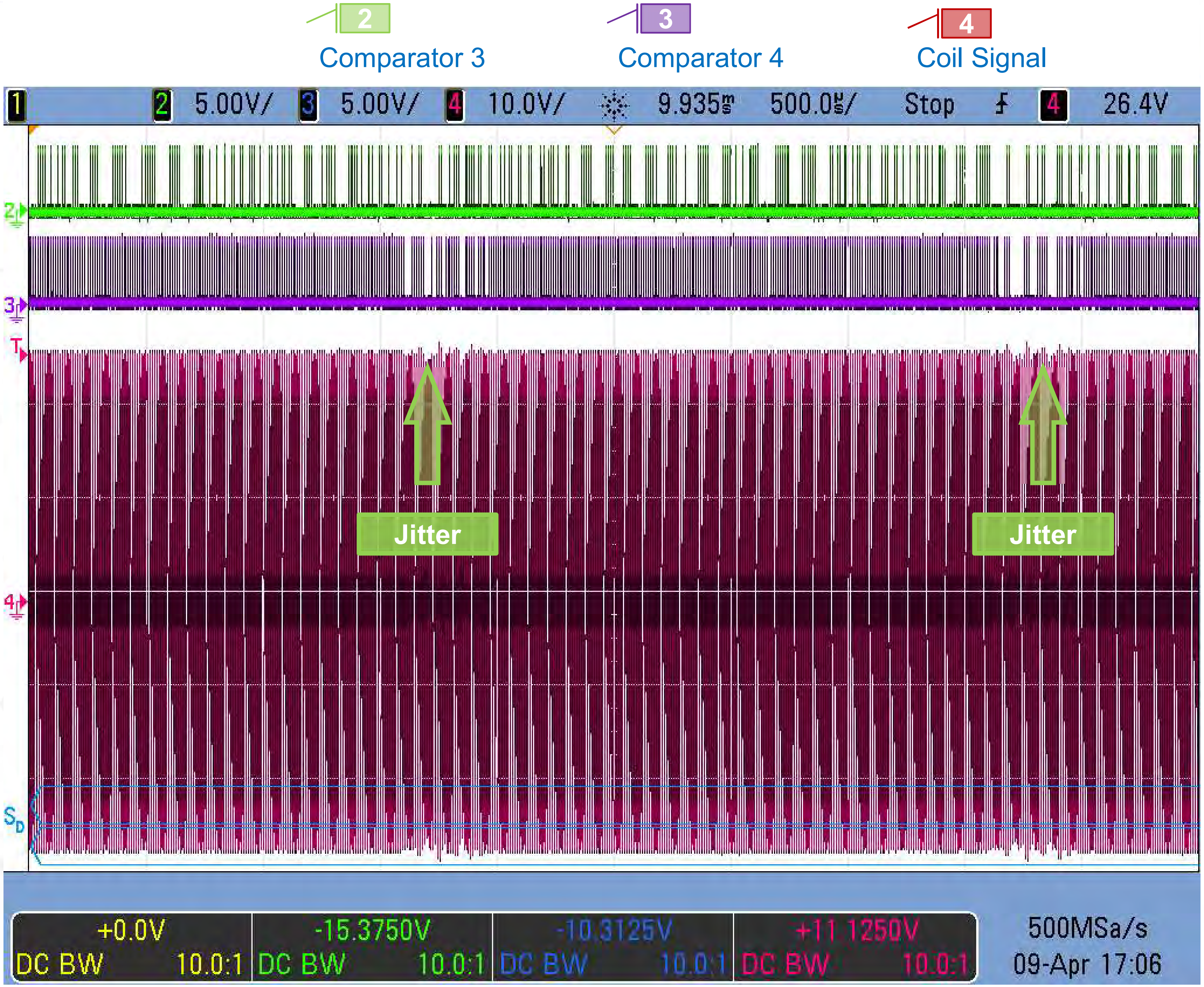
Y10. Circuit configuration for demodulating signal



Y11. Configuration for DAC3 & DAC4 calibration



Y12. Analog Modulation Signal is Resolved into Digital Data Stream

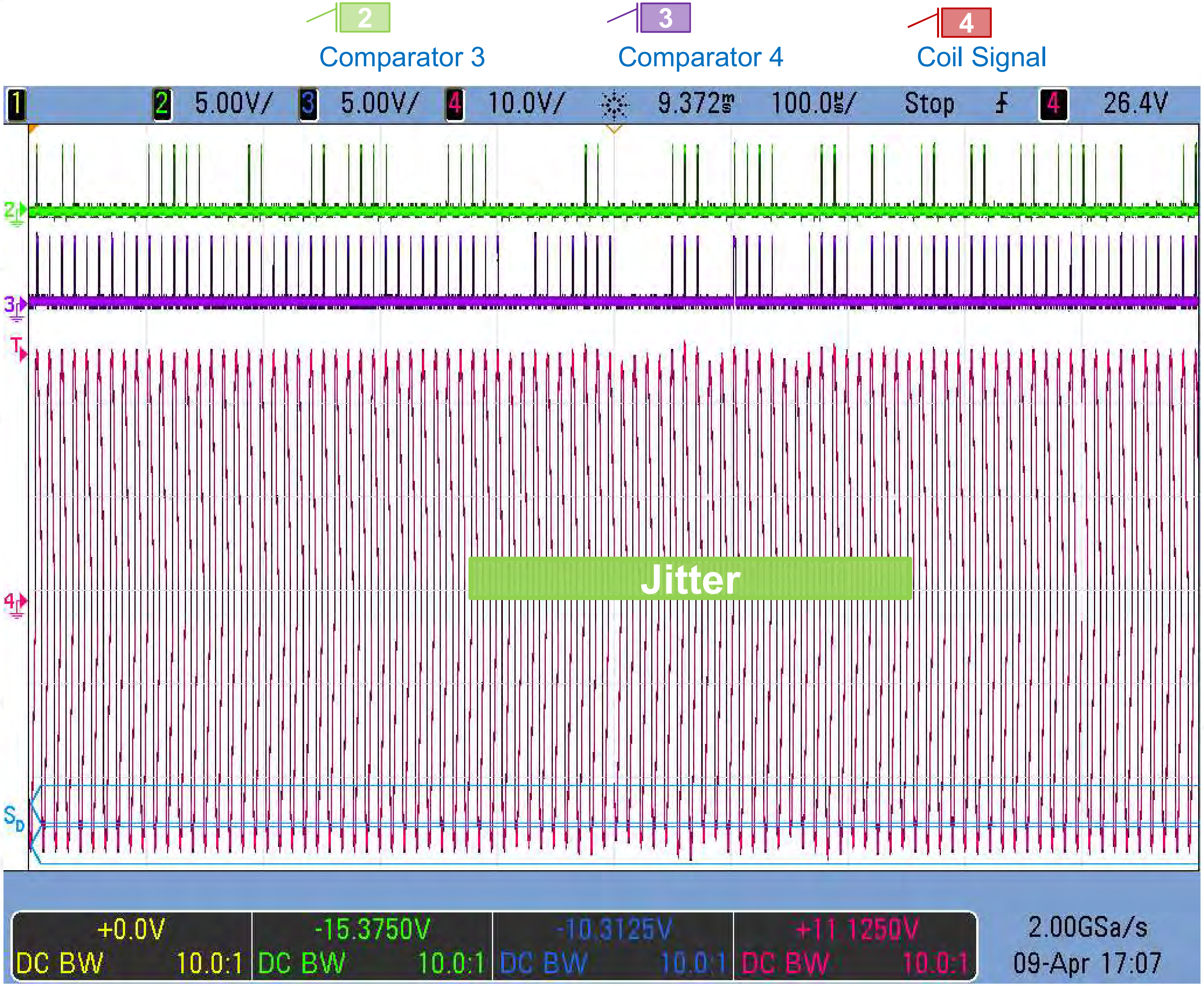


The PGA is set to 4X, a small amplification signal, and then sent to ACMP3&4 for analysis. ACMP3 is used with DAC3 to track the signal level. If there is a trigger in the current cycle, the level should be raised, and if it is not triggered, the level should be lowered. The result is that DAC3 will fluctuate at the peak value of the resonant signal.

DAC4 is set by subtracting one discriminant value from DAC3. In normal state, DAC4 will trigger during every cycle, but when the signal suddenly drops, DAC4 will not trigger, the difference between DAC4 and DAC3 is the sensitivity of signal analysis.

If the difference is large, the amplitude of the sudden drop of the signal will be more, so that the DAC4 will not trigger.

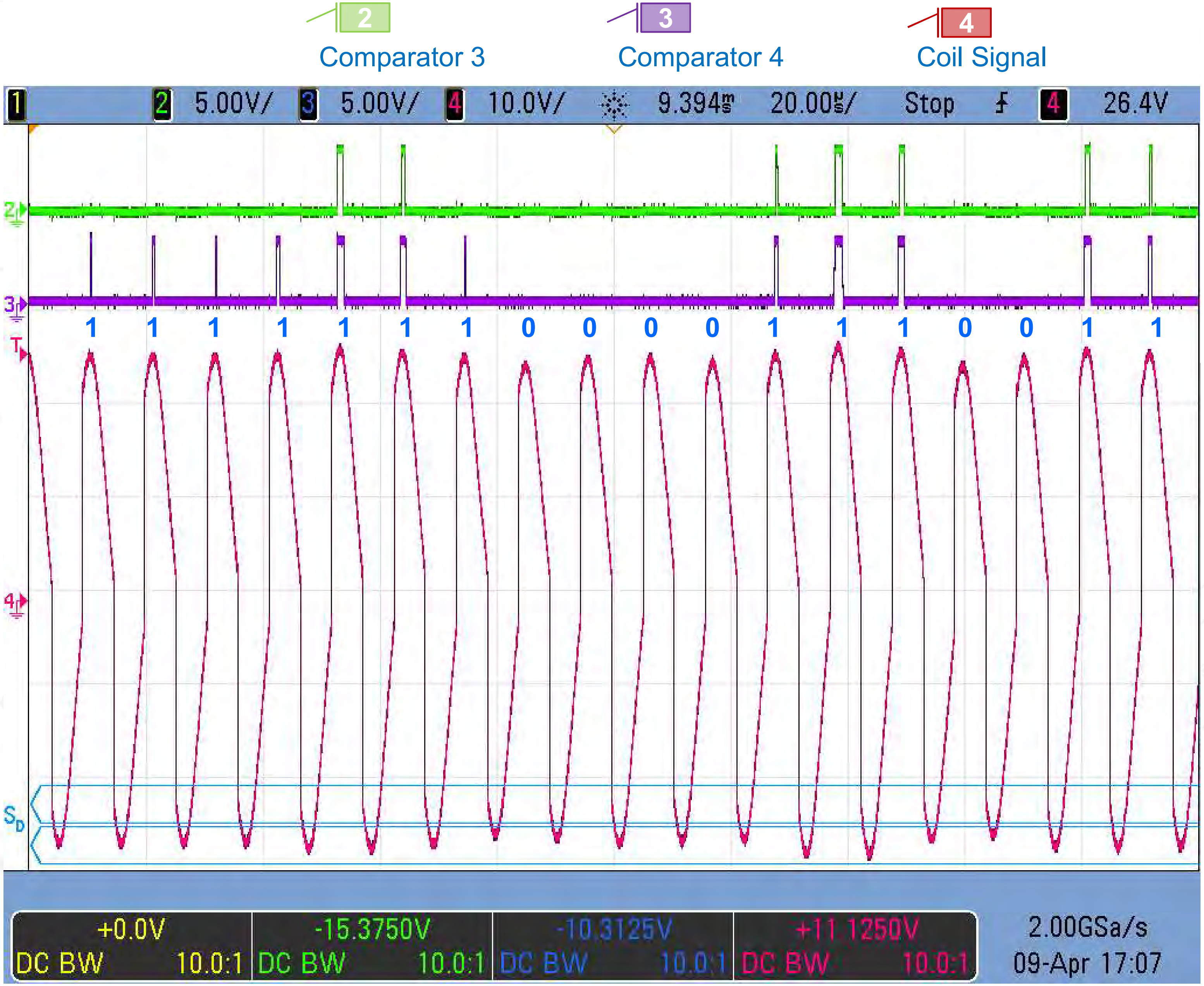
Y13. Analog Modulation Signal is Resolved into Digital Data Stream



The coil resonance signal is processed in units of PWM cycles. After the end of the previous cycle, the AC3IF and AC4IF are used as indicators for the occurrence of over-trigger at the beginning of each cycle. The result is transferred to the customized RAM block and analyzed.

The analysis software mainly finds the segment where ACMP4 does not trigger, and judges whether there is a feature of the swaying signal. If there is such a feature, it is transmitted to the corresponding decoding software for processing.

Y14. Analog Modulation Signal is Resolved into Digital Data Stream



This design is a no-filter direct sampling. It is suitable to analyze small jitter modulation signals. The modulation amplitude is much smaller than that of the QI system. The current DAC3 and DAC4 signal tracking mechanism is designed for finding jitter signals.

Y15. From Jitter Signal to Data Decoding Program Architecture Diagram

__PWMSpEventMatchInterrupt:
IPL=6 Interrupted once per PWM cycle
Rotate the state of the previous AC3IF and AC4IF to the trigger state queue store

Trigger Status of Comparator`s Queue Store

CODE_C3M_QUEUE_0
0101010101010101 ← RLC ← AC3IF

CODE_C4L_QUEUE_0
1111111111111111 ← RLC ← AC4IF

__PWM1Interrupt:
IPL=5 Interrupted once per PWM cycle
The decoder checks trigger status and whether all parts of the queue is triggered. If any part is not triggered, please mark it into the untrigger queue.

Untrigger Status`s Queue Store

CODE_SHAKE_QUE_1 ← CODE_SHAKE_QUE_0 ← RLC ← Judge the untrigger
0000000000000000 | 0000000000000000

__T3Interrupt:
IPL=2 Interrupted once per 0.25ms
Mark the jitter signal feature into the queue, then analyze and decode it

Characteristics of Jitter Signals

FG15_CODE
#CODE_C3C4_TMR3 ← BSET ← Determine the characteristics of jitter signals

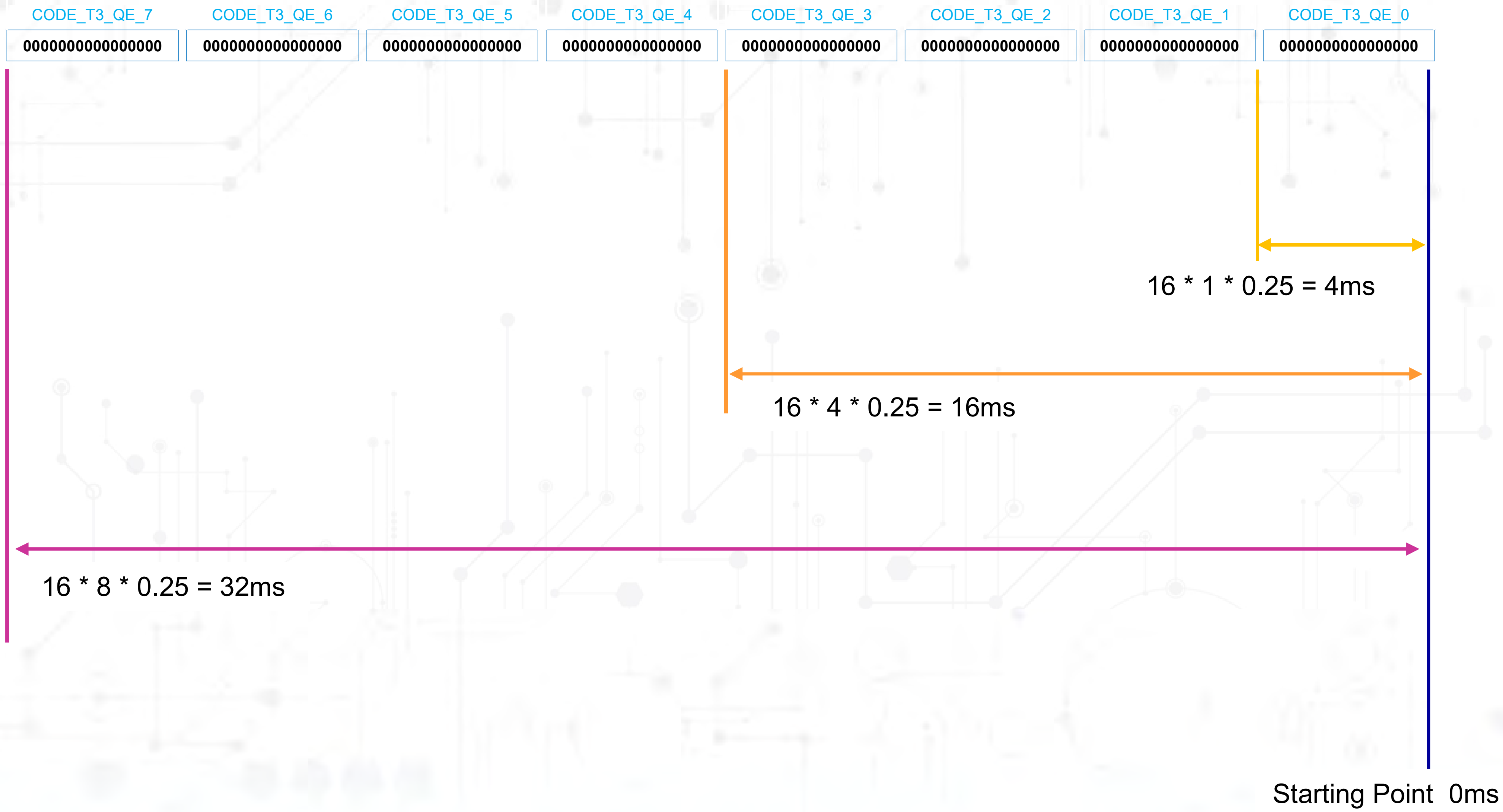
RRC

CODE_T3_QE_7	CODE_T3_QE_6	CODE_T3_QE_5	CODE_T3_QE_4	CODE_T3_QE_3	CODE_T3_QE_2	CODE_T3_QE_1	CODE_T3_QE_0
0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000

RRC →

Queue1 for jitter signals

Y16. Corresponding Relationship Between Jitter Signal Queue and Real Time



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Y17. The Length of Time of the Encoding of Corresponding Data

CODE_T3_QE_7	CODE_T3_QE_6	CODE_T3_QE_5	CODE_T3_QE_4	CODE_T3_QE_3	CODE_T3_QE_2	CODE_T3_QE_1	CODE_T3_QE_0
0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000	0000000000000000

P=0 2.75	DATA = 00000000 <Bit0 > 2ms * 8 = 16ms	START 2.5ms

Minimum length of time for data encoding:
2.5+16+2.75=21.25ms

P=0 2.75	DATA = 11111111 <Bit0 > 3ms * 8 = 24ms	START 2.5ms

Maximum length of time for data encoding:
2.5+24+2.75=29.25ms

	Time of Length	Number of Bits of Queue of the Corresponding TMR3
Start	2.5 ms	10
Data Bit0	2 ms	8
Data Bit1	3 ms	12
Parity Bit0	2.75 ms	9
Parity Bit1	3.25 ms	13

Y18. Convert from RX ADC to Encode , Decode and Calculate in TX

After the rectifier, the voltage of receiver	32V
Divider resistance of B3`s voltage to be measured	300KΩ//40.2KΩ
Voltage on the B3 ADC PIN	3.78
Transmission Result of B3 ADC(8BIT)	194
Transmit the ADC Value to binary bit	1100 0010
Exchange Between Two High and Low Bits for Transmitted Data	**0010 1100**

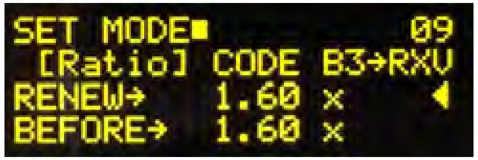
```
MOV     CODE_B3_CAL,W3
SWAP.B  W3
MOV     W3,CODE_B3
……….

MOV     CODE_B3,W0
MOV     EED_RAM_DB_09,W1

MUL.UU  W0,W1,W2

MOV     #100,W12
MOV     RCOUNT,W5
REPEAT  #17
DIV.SD  W2,W12
MOV     W5,RCOUNT

MOV     W0,CODE_B3_RXV
```

The received data is 00010 1100
Exchange between two high and low bits
to originate it from the data which should be transmitted

The value in EED_RAM_DB_09 is a preset parameter
It is the adjusted value of the sample after production.
Set page 1.60X and the content of its register is 160

The calculation method is as follows: ADC data * 160 = 194 * 160 = 31040
After it is divided by 100, the result is 310. The voltage displayed on the TX display board is 31.0V.

There is some differences with the theoretical value of 32.0V. This has some relationship with the measurement error of B3 itself.
The voltage on the TX display board is very close to the true voltage on the RX.

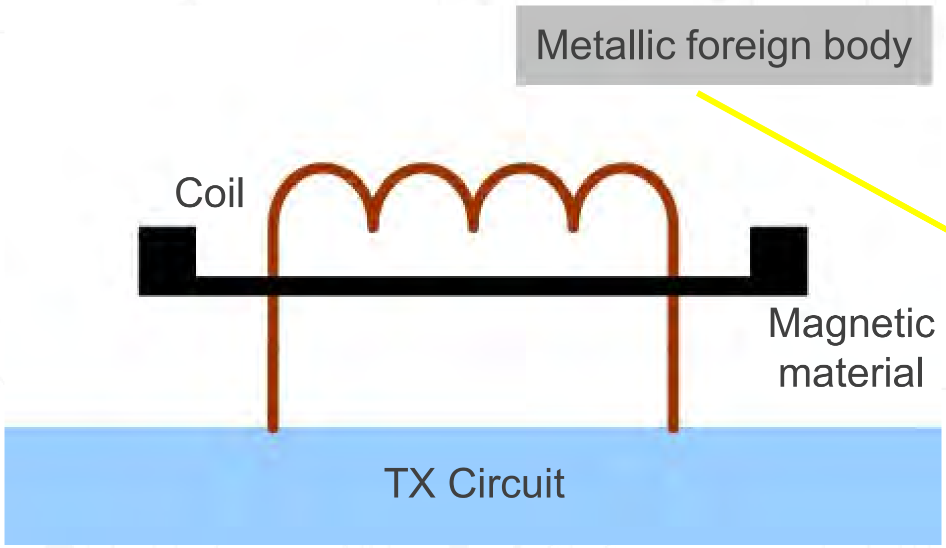


[Ratio] CODE B3→RXV	The multiplying power switched from the value in the data coding to the voltage on the B3

Z01. Foreign Object Detection (FOD)

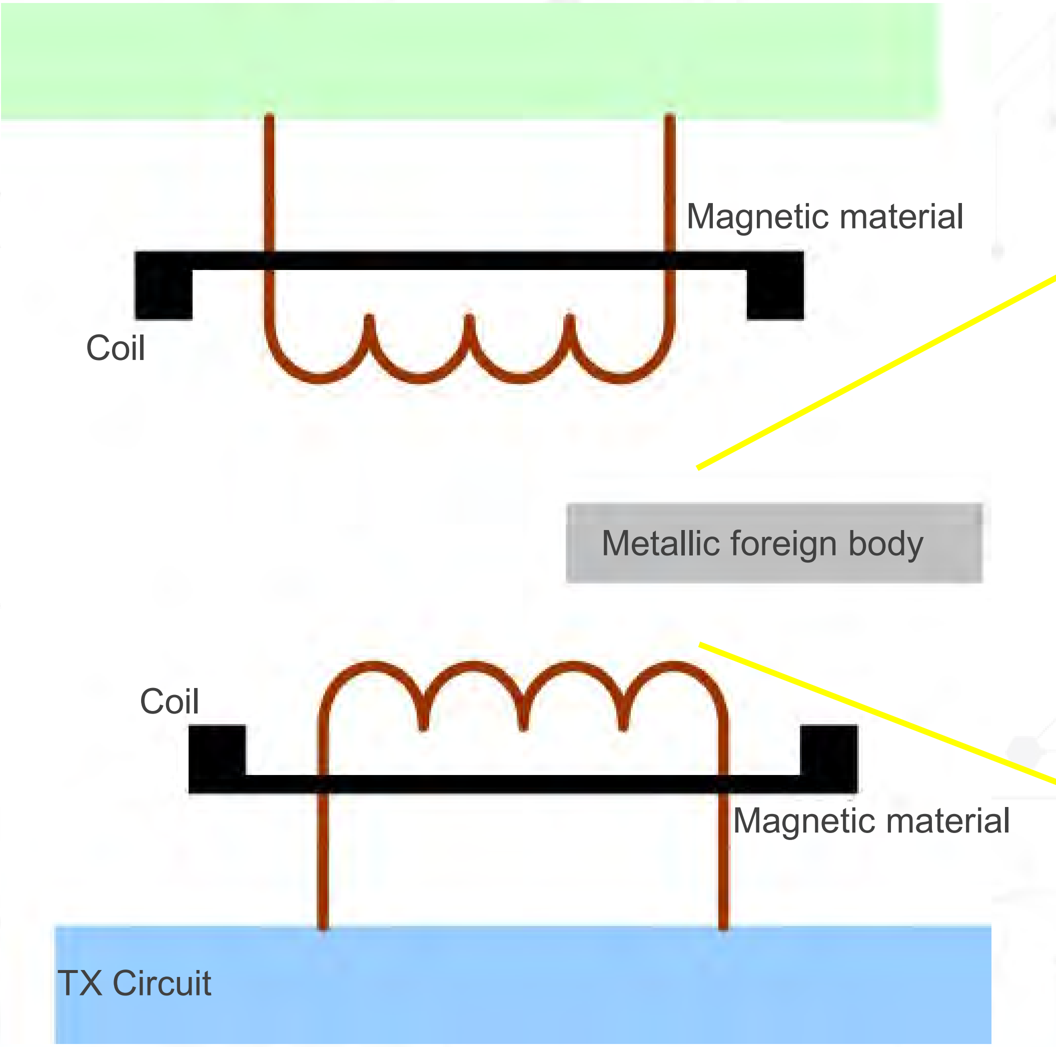
Types of Foreign Object	Detection Method	Measures for Detected Foreign Objects
A. Before detecting RX; there is a metalic foreign object on the TX coil or the object is attached to the RX coil	In the standby mode, the TX coil periodically measures the resonant frequency of the coil and length of time for the self-attenuation of the signal on the coil after driving the oscillation reaching to a fixed ratio , and uses this length to determine whether there is a metalic foreign object.	Do not start power transmission
B. After the detector for RX and TX is initiated; a metalic foreign object is interspersed between two coils.	In the process of power transmission, the driver switch will be interrupted for a short time. The coil will enter the short-time self-attenuation phase, and then the peak height of several cycles will be measured. Use this data to analyze whether there is any metalic foreign object.	Cut off the power supply of TX
C. Before detecting RX; there is an NFC device on the TX coil	Add a TX auxiliary coil. Periodically send a 13.56MHz oscillator signal to monitor the signal to analyze whether there is an NFC device.	Do not start power transmission

Z02. Metallic foreign body can be identified through the variations in the TX coil inductance



Metallic objects on the coil surface will reduce its inductance
Inductance changes = Q value changes?

Z03. TX coil inductance will be affected by the magnetic material used in RX coil



The closer to the magnetic material used in RX, the greater the TX coil inductance will be

Offset is unable to define the relationship between the TX coil inductance and the metallic foreign body

Metallic objects on the coil surface will reduce its inductance