Measure frequencies up to 6GHz and higher...

High Performance RF PRESCALER

by NICHOLAS VINEN

Would you like to measure frequencies up to 6GHz or more... but your frequency counter is not in the race? Well, if you already have a frequency counter which will measure up to 10MHz or so, you can add this prescaler to provide a *dramatic* increase in performance. And it has selectable frequency division ratios of 1000:1, 200:1, 100:1 or 10:1 to make it especially versatile.

A **frequency counter** is a very handy tool, even if it's one that's just built into a digital multimeter (DMM). Some DMMs contain frequency counters that will work up to 10MHz or more.

If you have one of those, or any other frequency counter (perhaps you built our low-cost 50MHz frequency meter from the November 2008 issue) – you can now have the facility to measure frequencies far above that range.

After all, there are lots of devices these days that operate at high frequencies – for example 433MHz, 900MHz, 2.4GHz or even 5.6GHz – so it's quite likely that you will soon want to measure the frequency of a signal and your cheap counter just won't be able to handle it. But now you can combine your existing frequency meter with our new *RF Prescaler* and you can get up into the gigahertz range.

The new *RF Prescaler* is housed in a tiny diecast aluminium case with two BNC output sockets and one SMA input socket. It also has a tiny 4-position slide switch to select the division ratio of 1000:1, 200:1, 100:1 or 10:1.

Set it to 1000:1 and connect it between the signal source and your meter and the 2.4GHz signal becomes 2.4MHz; easy for your meter to read and easy to convert in your head, since you just need to swap the units.

Operating principle

The basic arrangement of the *RF Prescaler* is shown in the block diagram of Fig.1 opposite. The source signal is applied to the 50Ω input connector at left, and then AC-coupled to IC1. This monolithic amplifier IC is essentially just a high-frequency Darlington transistor with biasing resistors and its input and output are both matched to 50Ω. 3.4V DC is fed to its collector via an inductor.

The output signal from the collector of IC1 is then AC-coupled to IC2, an identical amplifier, giving 22-34dB of signal boost in total, depending on frequency. The two amplifier stages are included to help make up for any signal loss in the input cabling and to give the *RF Prescaler* good sensitivity.

The output from IC2 is then fed to one of the differential inputs of a high-performance divide-by-five counter, IC3. The other differential input of IC3 is AC-coupled to ground since we don't actually have a differential signal at this point. IC3 is the most critical part of this circuit as it must reduce the very high frequency input signal down to something more manageable, ie, it gives a 1.2GHz output for a 6GHz input.

The output of IC3 is AC-coupled to another counter IC (IC4). This is programmable and can divide the frequency by a value anywhere between two and 256. Four different ratios are available, selected by slide switch S1: 2, 20, 40 and 200. These give overall division ratios (including the divide-by-five action of IC3) of 10, 100, 200 or 1000.

The output of IC4 is also differential, so these signals are fed to the bases of two PNP transistors which form a long-tailed pair. Their emitters are connected to the two output BNC connectors via impedance-matching resistor networks, which give an output impedance of 75Ω. Either or both outputs can then be fed to a frequency counter with a 50Ω or 75Ω input impedance. Or you could use one output to drive a frequency counter while the other drives an oscilloscope.

To handle the high frequencies involved, IC4 is an ECL (emitter-coupled logic) device with a maximum recommended operating frequency of 1.2GHz, although it will typically work up to 1.4GHz. IC1, IC2 and IC3 must all handle the full input frequency; so they use heterojunction bipolar transistors (HBTs) to achieve operation up to around 8GHz.

IC1 and IC2 are made from indium gallium phosphide (InGaP) semiconductor material, rather than silicon, because electrons move through it more quickly. IC3 also uses InGaP, together with gallium arsenide (GaAs) semiconducting material.

The use of different semiconductor materials for the emitter-base and base-collector junctions allows the base to be much more heavily doped without creating excessive hole injection from the base to emitter. The heavier doping reduces the base resistance while maintaining gain. This is what the term 'heterojunction' refers to; ie, the fact that the transistor junctions are made from two *different* types of semiconductor.

The operation of the circuit is shown in the scope grab labelled Fig.2. The *RF Prescaler* has been set to its minimum 10:1 overall division ratio to better illustrate its operation. A 20MHz, 35mV RMS signal was applied to the unit and the output of amplifier stage IC2 is shown at the bottom of the screen in blue, with an amplitude of a little over 1V RMS. Overall gain is therefore 29dB [$20\log_{10}(1000 \div 35)$], within the range expected.

The output of divide-by-five prescaler IC3 is shown just above it in pink, and this is a fairly clean 4MHz square wave with an amplitude of about 500mV peak-to-peak. The signal from output connectors CON2 and CON3 are shown in green and yellow above, with the expected frequency of 2MHz and a peak-to-peak voltage of around 300mV.

Setting a division ratio of 100:1, 200:1 or 1000:1, the duty cycle of the outputs drops below 50%. The output pulse width is normally five times the input signal period, ie, with a 5GHz input, the output pulses are at least 1ns.

Fig.3 shows the unit operating with a 1000:1 division ratio and a 100MHz, 10mV RMS input signal. The mauve trace shows the output of amplifier IC2, with an RMS amplitude of 300mV, indicating a gain of around 29.5dB. As you can see, the output pulses are around 50ns and the output frequency is 99.99kHz, indicating that the input is actually just a little below 100MHz (ie, around 99.99MHz).

Features and Specifications

Input frequency range ......5MHz-6GHz; typical operation to 7GHz
Input ....SMA, 50Ω
Input sensitivity ....<12mV RMS 6-3500MHz; <130mV RMS 5MHz-7GHz (typical; see Fig.6)
Division ratio ....selectable; 1000:1, 200:1, 100:1 or 10:1
Outputs ....2 x BNC, 50/75Ω, 180° out of phase
Output amplitude ....typically 300mV peak-to-peak into 50Ω
Output duty cycle ....approximately 50% (10:1), 5% (100:1), 2.5% (200:1), 0.5% (1000:1)
Output overshoot ....<10%
Power supply ....9V DC/500mA plugpack or 5V DC/500mA (microUSB); typically 375-450mA, quiescent ~375mA

Circuit description

The complete circuit of the 1000:1 *RF Prescaler* is shown in Fig.4. Input SMA connector CON1 is shown at left; depending on the exact model used, this can handle signals up to 20GHz. Low-capacitance schottky diodes D1 and D2 clamp the signal amplitude to no more than a few hundred millivolts to protect the rest of the circuit from a signal with too much amplitude. The signal is then AC-coupled via a 10nF C0G capacitor to the first amplifier, IC1.

IC1 is an ERA-2SM+ which provides around 16dB of gain at 1GHz, falling to 10.7dB at 6GHz. Its input impedance is 50Ω, so no termination resistors are required.

DC power is fed in via RF inductor L1, an ADCH80-A+, which maintains significant inductance up to 10GHz. It isolates the DC power supply from the AC signal present at output pin 3.

The 10nF bypass capacitor connected immediately adjacent to L1 helps to prevent any residual RF signal which may be coupled across L1's small interwinding capacitance from passing into the DC power supply.

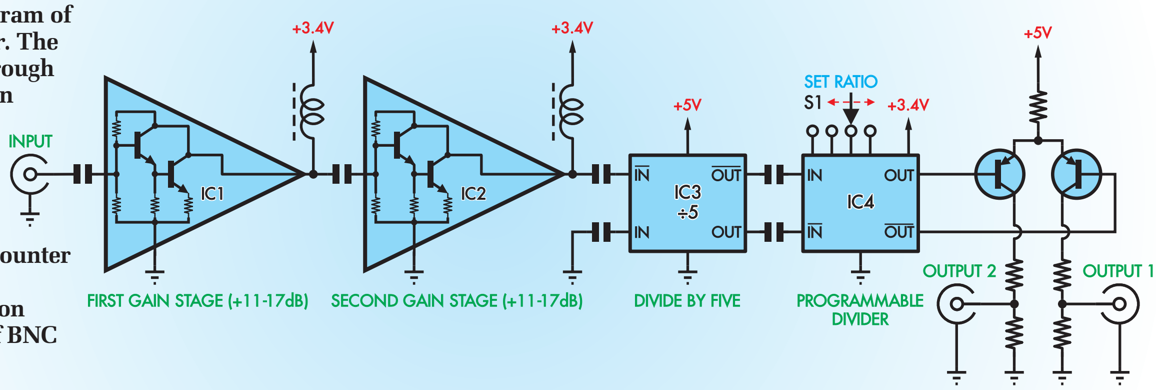
As the output impedance of IC1 is also 50Ω, we can feed its output signal directly to IC2 via another 10nF capacitor. The amplification stages comprising IC1 and L1 and IC2 and L2 are identical. Both amplifiers have a snubber network at their output comprising 33Ω resistors and 100pF capacitors. These help prevent instability when operating at around 4-4.5GHz.

The output from IC2 is fed to pin 3 of IC3 via another 10nF AC-coupling capacitor. IC3 is the HMC438MS8GE RF divide-by-5 counter and its differential input pins 2 and 3 are each internally biased and matched to 50Ω. As mentioned earlier, the other input terminal at pin 2 is connected to ground via an identical 10nF capacitor. Thus, this pin will sit at a DC level determined by IC3's internal biasing network.

IC3 runs from a 5V supply which is smoothed by a low-pass filter comprising a 47µH inductor and parallel 10µF and 10nF capacitors. The 10µF capacitor provides bulk bypassing while the 10nF C0G capacitor has a much lower effective series inductance (ESL) and thus will be more effective at filtering out higher frequencies.

This filter helps prevent any high-frequency signals which may be present in the 5V power supply from upsetting the operation of IC3, and also prevents any modulation of its own supply current from being fed back into other components.

Fig.1: block diagram of the *RF Prescaler*. The signal passes through two amplification stages, then a differential divide-by-five prescaler, followed by a programmable counter and then a dual voltage conversion stage to a pair of BNC outputs.



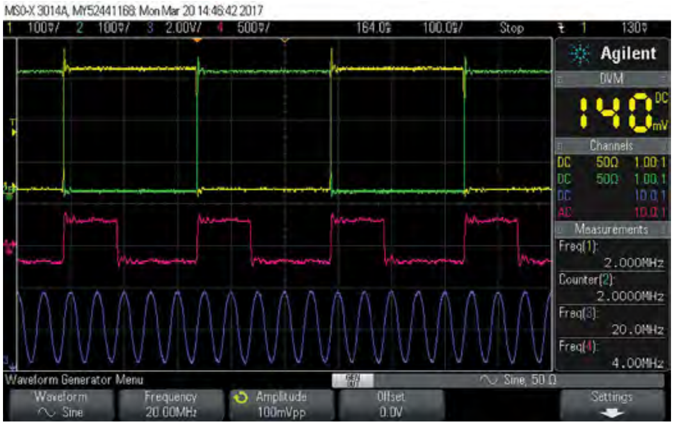


Fig.2: the amplified 20MHz input signal is shown at bottom in blue, followed by the 1/5 (4MHz) frequency signal above in pink and the 1/10 (2MHz) output signals at top, in yellow and green.

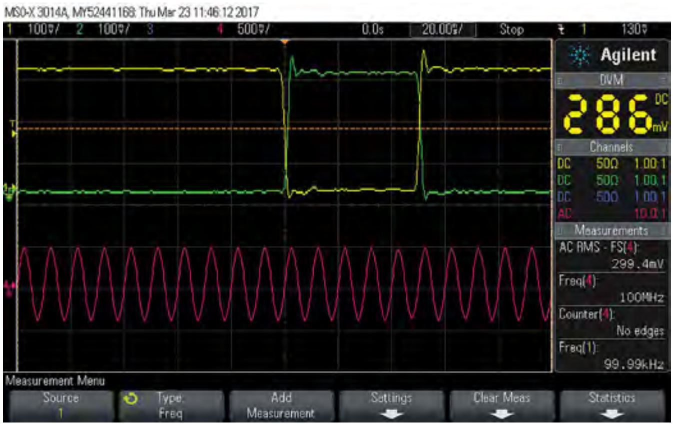


Fig.3: the pink trace shows the output of amplifier IC2 when fed with a 100MHz sinewave, and at top, the two outputs at 1/1000 the frequency, ie, 100kHz. The output pulses are around 50ns long.

IC3 can operate from very low frequencies (practically DC) up to around 7.5GHz, as shown in Fig.5. The upper limits shown here are not an issue since the 'saturated output power' of IC2, which provides the input signal for IC3, is 14dBm at 100MHz, 13dBm at 2GHz and 12dBm at 4GHz.

Hence, IC2 is incapable of producing a signal with an amplitude above that which IC3 can handle; we don't have data above 5GHz, but it seems probable that its output power is no more than 10dBm above this frequency.

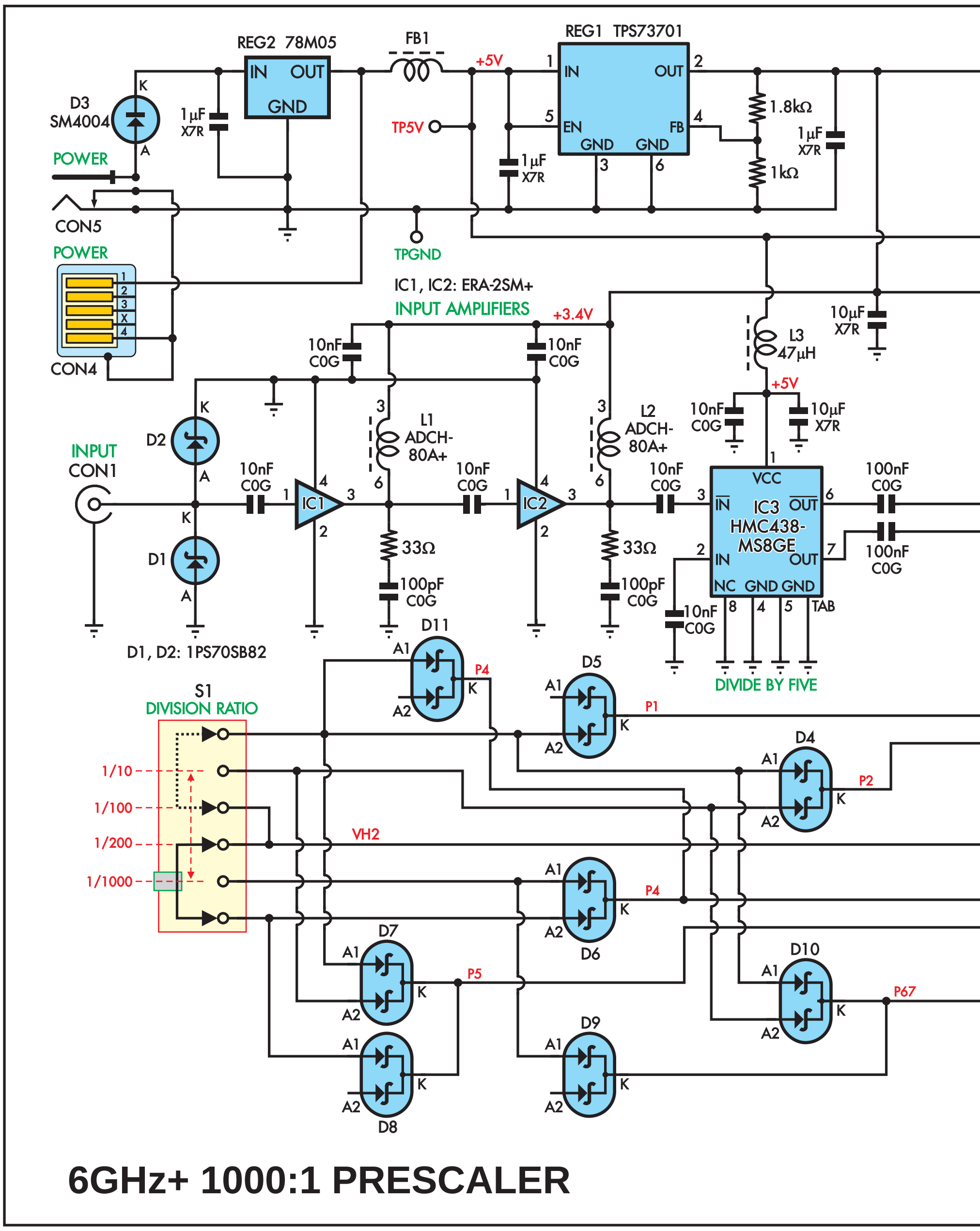
The lower signal limit shown in Fig.5, combined with the gain from IC1 and IC2, means that the theoretical sensitivity of the *RF Prescaler* is around –49dBm at 1GHz, which equates to an input signal of well under 1mV RMS. However, keep in mind that some of the input signal will be lost in the cabling and due to the 50Ω termination of the input, so in reality a 1mV signal would be marginal.

IC3 produces two output signals at one fifth its input frequency, with opposite phases, from pins 6 and 7. At low frequencies these are fairly square, although inevitably they become more sinewave-like at higher frequencies. These are coupled to another divider (IC4) via two 100nF capacitors. We're using higher value capacitors in these positions due to the lower frequency here compared to the input signal.

By extending the low frequency response of the unit, we reduce the need to constantly bypass the unit if you're measuring signals over a wide range of frequencies.

Programmable counter

IC4 is an eight-bit counter, counting from 0 to 255 (by default) and then going to zero again. If left in this default configuration (with most of the digital inputs open-circuit since they have internal pull-downs), the differential outputs C_{OUT} and $\overline{C_{OUT}}$ will produce pulses at a frequency 1/256th the input frequency ($256 = 2^8$). However, you can set IC4's division ratio to any value from 2 to 256. To do this, we set the states of input pins P_0-P_7 to an 8-bit digital value and pull the T_{CLD} input high. Every time the counter rolls over, rather than being reset to zero, it's loaded with the digital value from the P0-P7 pins.



Say we want an overall division ratio of 100. Since IC3 divides the input frequency by five, IC4 must divide the frequency by a factor of 20. To do this, we set P0-P7 to the binary value of 236 (256–20). Since counting now starts at 236, after 19 pulses, it reaches 255 (236+19) and so requires just one more pulse to roll over. Hence, it divides its input frequency by 20.

Selection of division ratios

As noted above, we're using a miniature 4-position horizontal slide switch (S1) to select the division ratios. This particular switch is a little unusual in that it has six pins and it works by bridging two of the pins, depending on the position of the switch, as depicted in the circuit diagram. For example, when in the 1/1000 position, the fourth and sixth pins are bridged.

We have arranged diodes D4-D11 so that in this position, the VH_2 voltage on the middle two pins of the switch (which we'll explain in more detail later) is applied to input pins P5 (via D8) and P4 (via D6), pulling those inputs high. Input P3 is permanently tied high. As a result, with P3, P4 and P5 high, the counter's initial binary value is 00111000 or 56 in decimal. Since 256 – 56 = 200 and 200 × 5 = 1000, we have the correct division ratio.

If you perform the same calculations for the other three switch positions, you will find that the pre-load counter values are 216 (256 – 40), 236 (256 – 20) and 254 (256 – 2).

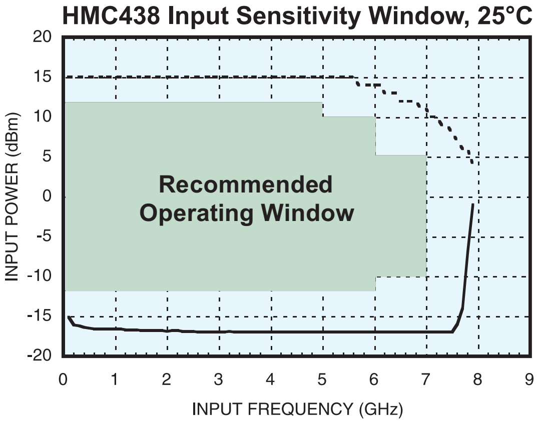


Fig.5: the recommended input power level for prescaler IC3 based on signal frequency. Keep in mind that IC3 is preceded by two amplifier stages for improved sensitivity.

ECL voltage levels

As mentioned earlier, IC4 is an ECL (emitter-coupled logic) device; a technology which has been used for decades for very high speed logic. ECL devices are bipolar transistors made from plain old doped silicon.

Despite this, these transistors are arranged in such a way to allow operation at frequencies over 1GHz.

This is because the transistors are biased so that they are always conducting, with their conductance being varied to produce different digital states, rather than being switched on and off. In a sense, this means that they process digital information in an analogue manner. As a result, ECL input and output voltages swing over a much more limited range than CMOS or TTL.

In the case of the MC100EP016A, the supply voltage is 3.0-3.6V and the average signal level is around 1V below this, ie, 2.0-2.6V, depending on the exact supply voltage. When a pin state changes between one and zero, typically its voltage will shift by around 0.7V. Assuming a 3.3V supply, a logic high level may be around 2.65V while a logic low would be around 1.95V.

Pin 24 on IC4 is labelled 'V_{BB}' and provides a reference voltage which is almost exactly halfway between the low and high stage voltages and may be used for comparison, to convert an ECL output to CMOS/TTL. We aren't using this pin though; we're using a different technique to produce the output signals, as will be explained later.

The somewhat unusual ECL levels do slightly complicate providing the correct input voltage levels for IC4. To achieve this, we have connected a resistive divider between the +3.4V rail and the 1.4V (VCC – 2V) rail to generate two additional voltage levels, VH_2 and VH_1. VH_2 is approximately +2.5V while VH_1 is approximately +2.3V.

VH_1 is therefore in the middle of the specified 'input high voltage' range for IC4 (with V_{CC}=3.4V) of 2.14-2.49V and so pins which are permanently tied high are held at this voltage, ie, TCLD (terminal count load; mentioned above), $\overline{PE}$ (the chip enable pin) and P3 (also mentioned above).

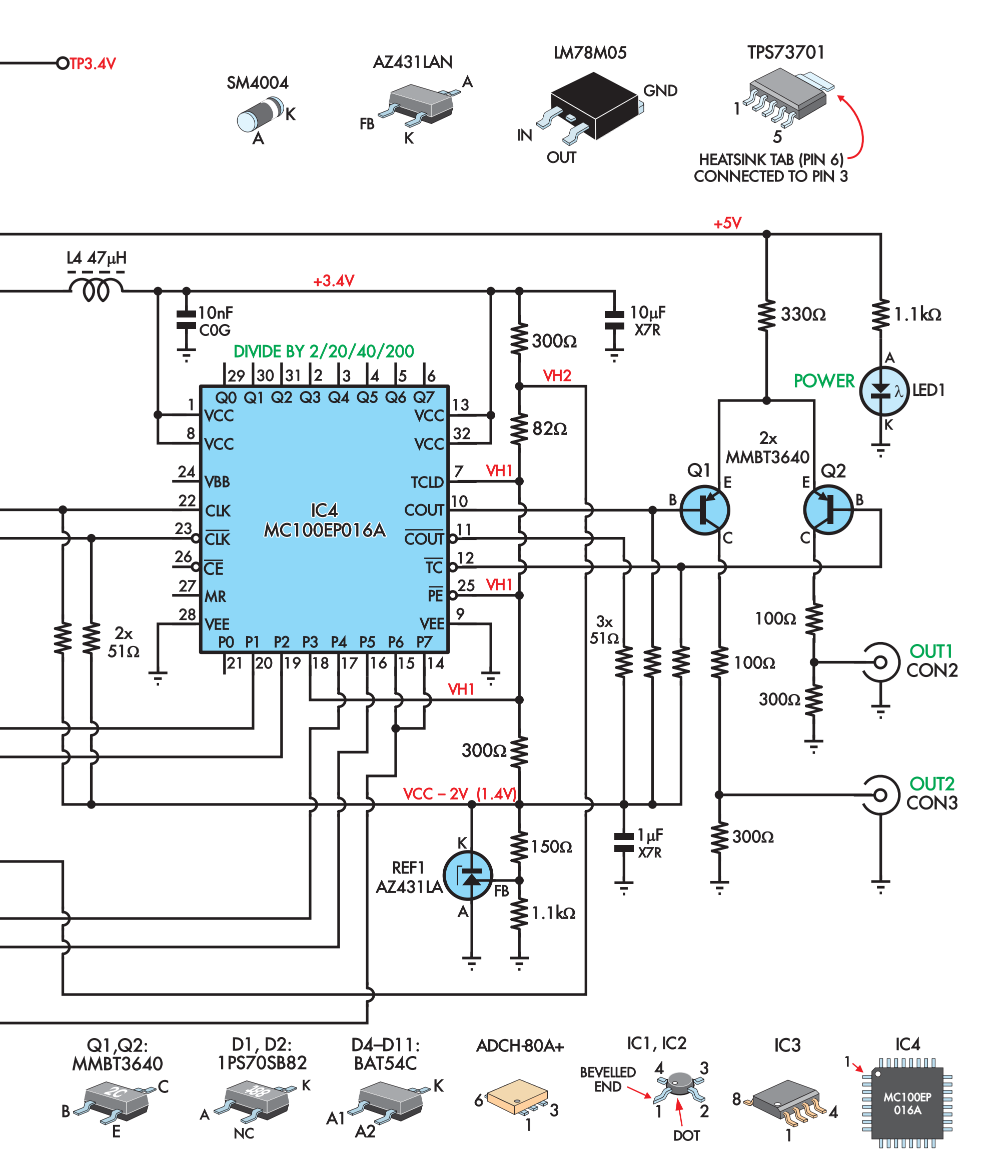


Fig.4: complete circuit for the *RF Prescaler*. The diode logic network comprising slide switch S1 and dual diodes D4-D11 configures IC4 for the selected division ratio.

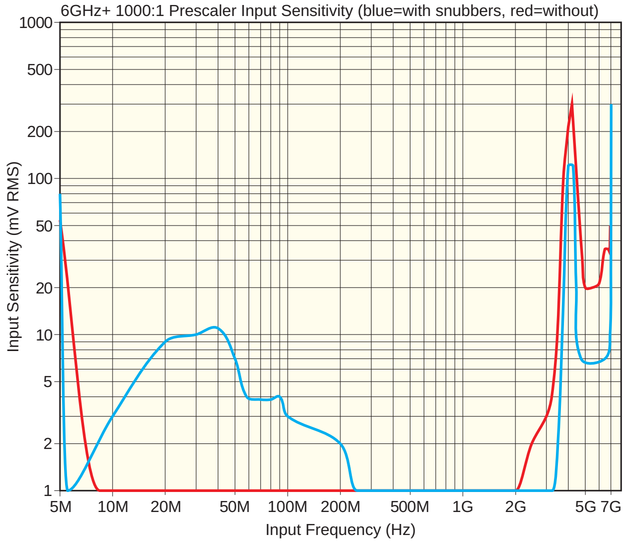


Fig.6: minimum input sensitivity for the *RF Prescaler*. Signal levels above this, up to about 1V RMS, should not be a problem. Below the level specified, it may operate with some jitter, or not at all. The blue curve is for the circuit as published, while the red curve shows its performance without the two snubber networks at the outputs of IC1 and IC2.

However, pins P1, P2 and P4-P7 are pulled high via a series of schottky diodes and switch S1, so VH_2 is connected to the anodes of these diodes rather than VH_1. This compensates for the voltage drop across the diodes, so that 2.3V is also applied to those pins when they are pulled high.

IC4's data sheet does not explain whether these inputs must be within the 'input high voltage' range, so we have played it safe and keep them within that range, rather than just tie them high (to +3.4V) and hope it works reliably.

The V_{CC}–2V (1.4V) rail which is used to derive VH_1 and VH_2 is generated by shunt regulator REF1. Its nominal voltage is 1.24V and the 150Ω/1.1kΩ resistive divider between its cathode, feedback input and anode sets the gain to 1.136 for an output of 1.41V (1.24V x 1.136).

This rail is also used to terminate the three main counter outputs of IC4 (COUT, $\overline{\text{COUT}}$ and $\overline{\text{TC}}$) via 51Ω resistors, in line with how the data sheet suggests they should be terminated to achieve the specified performance. REF1 can sink up to 100mA, which is more than enough for this application. The voltage across it is stabilised despite a high-frequency AC component to the current due to the 1µF bypass capacitor.

This same V_{CC}-2V rail is also used to DC-bias and terminate the CLK and $\overline{\text{CLK}}$ input signals for IC4 (at pins 22 and 23), via 51Ω resistors. Such low-value termination is done to ensure there's no overshoot or ringing overlaid on the signals from IC3, which might upset the operation of IC4.

Output stage

The differential output from IC4 is at pins 10 and 11 (C_{OUT} and $\overline{C_{OUT}}$) and being ECL outputs, these swing between about 1.95V and 2.65V. However, there is another output, $\overline{\text{TC}}$ at pin 12 which has a similar waveform to that at pin 11. We found its average DC voltage level more stable than that at pin 11, so we are using pins 10 and 12 as the differential outputs instead.

These are connected to a differential-to-single-ended conversion stage comprising 500MHz PNP transistors Q1 and Q2, which are arranged in a long-tailed pair. Since their emitters are joined together and supplied with current with a 330Ω fixed resistor from the 5V rail, the emitter voltage is determined by whichever base voltage is higher at the time. The bases of Q1 and Q2 are connected directly to the two outputs of IC4 mentioned above, pins 10 and 12.

Hence, whichever output is lower, the transistor it is driving is switched on harder, as it has a higher base-emitter voltage than the other. So when pin 10 of IC4 is lower, Q1 is switched on while Q2 is basically off, and when pin 12 is lower, Q2 is switched on while Q1 is basically off.

The collectors each have a total load resistance of 400Ω, arranged as a divider which reduces the collector signal voltage by 25% at output connectors CON2 and CON3, while providing an output impedance of 75Ω (ie, 100Ω in parallel with 300Ω). This results in an output voltage swing of around 2V peak-to-peak. However, when the output(s) are terminated with 50Ω or 75Ω, this is reduced to about 300mV peak-to-peak; sufficient to drive an external oscilloscope or frequency counter.

Power supply

For the power supply we recommend using a regulated 9V 500mA DC plug-pack, plugged into DC barrel connector CON5. This feeds 5V linear regulator REG1 via reverse-polarity protection diode D3, which in turn provides the 5V rail for IC3 and the output stage (Q1 and Q2) via a ferrite bead (FB1). FB1 prevents any high frequency modulation in the current draw of IC3 from radiating from the power supply lead.

The 5V rail is also applied to linear regulator REG2, which generates a 3.4V rail for IC1, IC2 and IC4. REG2 can either be an adjustable TPS73701 with 1.8kΩ and 1kΩ resistors connected to its feedback (FB) pin 4, as shown in Fig.4, or it can be a TPS73734 fixed 3.4V regulator.

If using the fixed regulator, omit the 1.8kΩ resistor and replace the 1kΩ resistor with a 10nF SMD capacitor, which gives it superior ripple rejection.

While we could have used a 3.3V fixed regulator, which is much more common than 3.4V, 3.4V is the ideal operating voltage for IC1 and IC2 (3.2-3.6V allowed) and is also suitable for IC4 (3.0-3.6V). Depending on tolerance, the output of a 3.3V regulator may be too low for proper operation of IC1 and IC2.

It's also possible to power the unit from a USB supply, via optional USB socket CON4. If both CON4 and CON5 are fitted, CON4 is automatically disconnected if a DC plug is inserted, by the switch integral to CON5.

While our unit successfully operated from a USB supply, because this supply is used to run IC3 directly, any significant high-frequency hash could interfere with its operation.

Since many USB chargers have quite poor regulation and high levels of hash, it's probably better to stick with the 9V supply option.

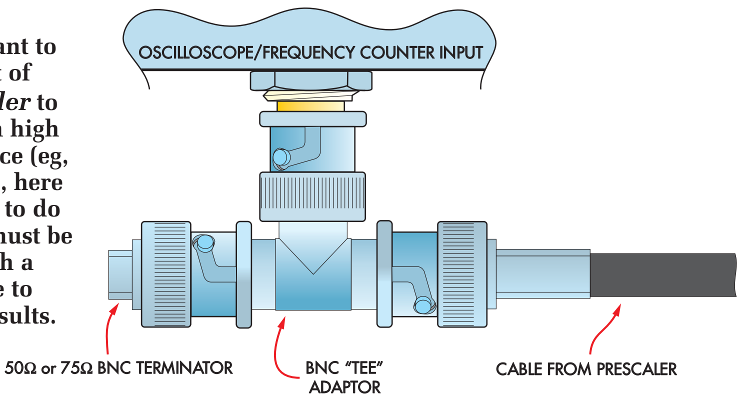


Fig.7: if you want to feed the output of the *RF Prescaler* to a device with a high input impedance (eg, 1MΩ or 10MΩ), here is the best way to do it. The signal must be terminated with a low impedance to get accurate results.

Apart from the four-position switch which selects the division ratio, there are no actual controls on the *RF Prescaler*. One edge has the SMA input socket (left), the division switch and the two BNC output sockets, one of which is 180° out of phase with the other. On the opposite side are the two power sockets – a 9V DC barrel socket (which we prefer) and a 5V micro USB socket (only one is used at any time) – if you only intend to use the 9V socket or the micro USB, the other can be left off the PCB, saving you a bit of drilling or filing.

Besides, drilling a round hole is a lot easier than cutting/filing a square hole!

Frequency limits

We've rated this *RF Prescaler* at '6GHz+' because as presented, it will definitely operate to at least 6GHz and probably up to 7GHz. The actual upper limit depends on the exact properties of ICs1-4 which are fitted to your board.

The signal first passes through amplifiers IC1 and IC2. These are rated to operate to 6GHz with a typical gain of 10.7dB at 6GHz; down from a peak of 16.4dB at lower frequencies (10-100MHz). Presumably, they will also provide gain for signal just above 6GHz but this is not specified in the data sheet. Our guess is they will operate to at least 6.5GHz with at least some gain and will probably pass signals to at least 7GHz.

IC3 can normally operate to at least 7.5GHz with no reduction in performance (see Fig.5) but sensitivity rapidly falls off above that and it's unlikely to work at 8GHz.

The data sheet for IC4 indicates that at standard room temperature, it will typically handle signals up to 1.4GHz and definitely up to 1.2GHz. That translates to 7GHz (1.4GHz × 5) typical input frequency and 6GHz (1.2GHz × 5) minimum guaranteed input frequency.

So you can see that with a bit of luck, the *RF Prescaler* should work up to 7GHz, albeit with reduced sensitivity.

Note that that you could replace the two ERA-2SM+ amplifiers with ERA-1SM+ amplifiers. These have a specified gain of 7.9dB at 6GHz and 8.2dB at 8GHz. However, do note that it's possible that IC4 won't handle these higher frequencies; after all, it's only guaranteed to work up to 1.2GHz. And the ERA-1SM+ has less gain at lower frequencies, for example, 12.1dB at 1GHz compared to 15.8dB for the ERA-2SM+. Hence our recommendation to use the ERA-2SM+ devices.

Construction

The *RF Prescaler* is built on a double-sided PCB which is available from the *EPE PCB SErvice*, coded 04112162, measuring 89 × 53.5mm. This is mounted in a diecast aluminium case. Almost all the components are SMDs, the exceptions being connectors CON-CON3 and CON5, switch S1 and power LED1. Use the PCB overlay diagram in Fig.8 as a guide during construction.

Start with IC4. You can use a standard soldering iron, as long as the tip is not too large, but we recommend that you purchase a small tube or syringe of flux paste and some solder wick if you don't already have some. Good light and a magnifier are also important.

Place a small amount of solder on one of the corner pads for IC4 and then orient the part on the board as shown in Fig.8. Pin 1 goes towards lower left – this should be indicated on the PCB silkscreen.

Once the IC is oriented correctly, heat the solder you applied to the corner pad and then carefully slide the IC into place and remove the heat. This process should take no more than a few seconds.

Now carefully check that the IC pins are centred on their pads. Check all four sides. Use magnification to make sure that all pins are properly centred on their pads. If not, re-heat the solder on that one pad and gently nudge the IC towards the correct position.

Repeat this process until you are happy that the IC is correctly located and check that its pin 1 is in the correct position before tack soldering the diagonally opposite pin.

Re-check that all the pins are correctly located; you can re-heat either solder joint at this point to make slight adjustments.

Now apply a thin layer of flux along all the IC pins and then apply solder to all the pins. Make sure you apply enough to get proper fillets. It's difficult to avoid bridging the pins at this point; what's most important is getting the solder to flow onto each pin and pad on the PCB.

Once all the pins have been soldered, apply another thin layer of flux paste and then use a piece of solder wick to remove any excess solder, especially where adjacent pins are bridged. Proceed carefully and re-apply flux paste if necessary.

When you have finished, clean off the flux residue (using either a proper flux solvent or ethyl alcohol/methylated spirits and a lint-free cloth) and examine the solder joints under good light and magnification to ensure they are all good and there are no more bridges left.

After soldering IC4, you can fit IC3 in the same manner. IC3 has smaller, more closely-spaced leads but there are only eight of them, on two sides of the IC. One additional thing you will have to take into consideration is that IC3 has a thermal pad on the underside and ideally, this should be soldered to the matching pad on the PCB.

If you have a hot air reflow system (lucky you!) this is quite easy, as it's just a matter of spreading some solder paste on the nine pads for this IC, putting it in position and then gently heating it until all the solder paste melts and reflows.

However, if you are just using a regular old soldering iron, you should spread a thin layer of solder paste on the large central pad, then drop the IC down into position and tack solder it in position.

After checking that its orientation and position are correct, solder the remaining leads using the same technique as for IC4. Then flip the board over and squirt some flux paste into the hole directly under IC3.

Melt some solder into this hole and heat it for several seconds. Remove heat and carefully check that IC3 is hot by quickly touching it with your finger.

This indicates that the solder has conducted enough heat through the hole to melt the solder paste you placed under it earlier.

If you're fitting microUSB connector CON4, do so now since its pins are hard to access once the other components are in place. This one is a little tricky because its pins are quite close together and despite the plastic locating posts, it's a little difficult to get the connector to sit in just the right position.

Start by putting a little flux paste on all the pads and pins for this device,

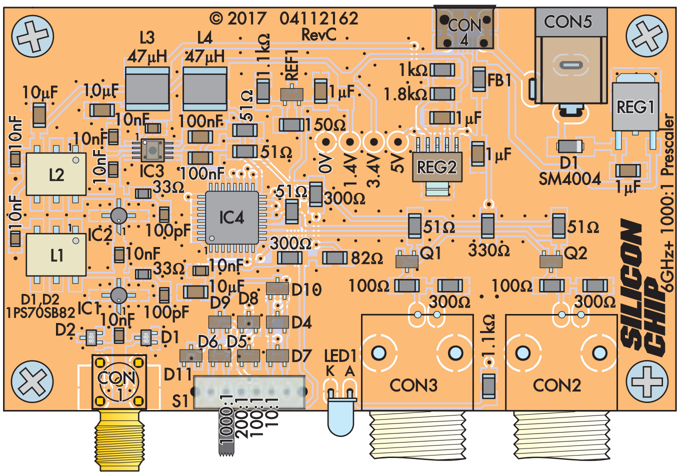


Fig.8: use this PCB overlay diagram as a guide to build the *RF Prescaler*. Start with IC4 and IC3 – these have the smallest pin spacings. Most of the remaining components are pretty easy to solder.

then drop it into place. Use a magnifying glass to check whether the pins are in the right location, then hold the device down with something heatproof (like a toothpick – not your finger!) and solder one of the large mounting lugs. This will take a few seconds as it will heat up the whole metal body while doing so.

Once you've formed a good solder joint on one of the mounting lugs, recheck that the signal pins are still located correctly. If they aren't, you will need to hold the socket with tweezers and nudge it into place while heating the solder.

You can then solder the remaining mounting lugs, followed by the signal pins and clean up any bridges between the pins using solder wick and a little extra flux paste. Use a magnifier to verify that all the signal pin solder joints are good before proceeding.

Remaining SMDs

The rest of the parts are quite easy to install as they have more widely spaced leads. Solder IC1 and IC2 next, making sure their 'pointy' pins are soldered to the pads marked for pin 1. Follow with L1 and L2, both of which are in six-pin packages. Their pin 1 dot should be oriented as shown in Fig.8.

Next on the list is REG1. This has one large pad and five small ones. The regulator itself has considerable thermal inertia, so spread a thin layer of flux paste on the large pad with a little extra paste on the smaller pads, drop REG1 in position and then tack solder one of the smaller pins (you can pre-tin the pad and heat it while sliding the part into place, if you like, as you did with IC4). You can clean these joints up with some additional flux paste and an application of solder wick.

Now for the large tab. Apply some solder to this tab and hold your iron in contact with both the regulator tab and PCB pad. You may need to hold it there for some time before the whole assembly heats up enough for the solder to flow down onto the board. Keep adding solder until the tab is covered and looks shiny, then remove the heat. Use a similar technique to fit REG2.

Inductors L3 and L4 are similarly quite large, so again, spread flux paste on each of their pads before soldering. You can then add some solder to one of the pads and slide the inductor into place while heating that solder.

Again, you may need to wait some time before the inductor heats up enough to slide fully into place and you can then add more solder until a nice, shiny fillet has formed. Let that cool down a little, then solder the opposite end, again waiting until it's hot enough to form a good joint (this should be quicker as both the inductor and PCB will retain significant heat).

The next components on the list are REF1, Q1, Q2 and diodes D4-D11. These are all in small 3-pin SOT-23 packages so don't get them mixed up. The eight diodes are all the same type. In each case, tack solder one pin, check that the pins are properly aligned, solder the other two pins and then refresh the initial pin. It's easier if you spread a little flux paste on the pads before soldering each part.

Now fit diodes D1 and D2, which are in similar but slightly smaller packages than D4-D11, followed by diode D3, which is in a two-pin rectangular or cylindrical package. Make sure its cathode stripe faces towards REG2 (indicated with a 'k' on the PCB). You can then fit all the ceramic capacitors and resistors to the board, as well as SMD ferrite bead FB1, where shown in Fig.8. Orientation is not critical for any of these.

Remember that if you're using a TPS73734 regulator, rather than the suggested TPS37301, you will need to omit the 1.8kΩ resistor and replace the 1kΩ resistor with a 10nF capacitor.

Through-hole components

With all the SMDs in place, you can now proceed to solder slide switch S1, SMA connector CON1, barrel connector CON5 (if being fitted) and BNC sockets CON2 and CON3. In each case, ensure the part is pushed down fully onto the PCB before soldering the pins. The larger metal connectors such as CON1 require quite a bit of heat to form good solder joints.

Note that the pads for CON1 are designed to allow either a right-angle or edge-mounting ('end launch') connector – we recommend using a right-angle connector like we did in our prototype, so that it lines up with BNC sockets CON2 and CON3.

Power indicator LED1 was not fitted to our prototype but we decided it would be handy and so have added it to the final version, located just to the left of output connectors CON2 and CON3. Bend its leads through 90° close to the base of the lens, so that the longest lead will go through the hole towards the right-hand side of the board, marked 'A' in Fig.8 and on the PCB. Solder it with around 6mm of lead length above the PCB, so that its lens lines up with CON1-CON3.

Initial testing and use

Ideally, you should connect an ammeter in series with the DC power supply the first time you fire up the *RF Prescaler*. Quiescent current should be close to 380mA (or 370mA on the 10:1 divider setting). Less than 350mA suggests that at least one device in the circuit is not getting sufficient voltage, while much more than 400mA possibly indicates a short circuit.

If the initial current drain is not in the range of 325-425mA, switch off immediately and carefully check the PCB for assembly faults, such as adjacent pins being bridged, bad solder joints or incorrectly placed or oriented components. Use good light, a magnifier and if necessary, clean flux (or other) residue off the board using methylated spirits or another similar solvent so that you can see it properly.

Assuming the current is in the right range, use a DMM to check the voltages at the three test points provided, labelled 1.4V, 3.4V and 5V. These are the voltages you should expect at each point. The 1.4V test point should be between 1.35V and 1.45V, the 3.4V test point between 3.35V and 3.45V, and the 5V test point around 4.75-5.25V (possibly slightly higher or lower if you're using the USB supply option).

If the 1.4V test point is off, that suggests a problem with REF1. If the 3.4V test point is off, you may have fitted incorrect divider resistors for REG2.

On our prototype, we used a TPS73701 (adjustable version of REG2) and found the 3.4V rail was a little low

Parts list – 1000:1 6GHz+ Prescaler

1 double-sided PCB, available from the *EPE PCB Service*, coded 04112162, 89 × 53.5mm
1 diecast aluminium case, 111 × 60 × 30mm
1 high-frequency SMD ferrite bead, 3216/1206 size (FB1)
2 Mini-Circuits ADCH-80A+ Wideband RF choke (L1,L2) (*available from* ***www.cseonline.com.au*** *or the* ***Silicon Chip Online Shop***)
2 47µH 6 × 6mm SMD inductors (L3,L4)
1 SMA right-angle through-hole or edge-mounting connector, 50Ω, >6GHz (CON1)
2 PCB-mount right-angle BNC sockets (CON2,CON3)
1 SMD microUSB socket (CON4) ***AND/OR***
1 PCB-mount 2.1mm or 2.5mm ID DC barrel socket (CON5)
1 C&K SK-14D01-G 6 PCB-mount right-angle SP4T micro slide switch (S1)
1 SMA male-to-BNC female adaptor (optional, for connecting BNC-equipped signal sources)
1 BNC T adaptor and 50Ω or 75Ω termination plug (optional, for driving high-impedance equipment)
1 9V DC regulated supply with plug to suit CON5 ***OR***
1 5V USB supply with Type-A to microUSB cable (see text)
4 M3 × 10mm pan-head machine screws and nuts
8 3mm ID 6mm OD 1mm thick Nylon washers
4 M3 Nylon nuts
4 small rubber feet (optional)

Semiconductors
2 Mini-Circuits ERA-2SM+ wideband RF amplifiers [Micro-X] (IC1,IC2) (*available from* ***www.cseonline.com.au*** *or the* ***Silicon Chip Online Shop***)
1 HMC438MS8GE 7GHz divide-by-five prescaler [MS8G] (IC3)
1 MC100EP016A 3.3V ECL 8-bit synchronous counter [LQFP-32] (IC4)
1 TPS73701DCQ (adjustable) or TPS73734DCQ (fixed) 1A low-dropout linear regulator (REG1)
1 78M05 5V 0.5A linear regulator [D-PAK] (REG2)
1 AZ431LANTR-G1DI 100mA 1.24V adjustable shunt reference [SOT-23] (REF1)
2 MMBT3640 12V 200mA 500MHz PNP transistors [SOT-23] (Q1,Q2)
1 3mm blue LED (LED1)
2 1PS70SB82 Schottky diodes [SOT-323/SC-70] (D1,D2)
1 S1G or equivalent 1A diode [SM-1/SMA] (D3)
8 BAT54C Schottky dual diodes [SOT-23] (D4-D11)

Capacitors (all SMD ceramic 3216/1206 size unless otherwise stated)
3 10µF 16V X7R
4 1µF 16V X7R
2 100nF 50V X7R
9 10nF 50V NP0/C0G, 2012/0805 size (one unused when REG1=TPS73701)
2 100pF 50V NP0/C0G, 2012/0805 size

Resistors (all SMD 3216/1206 size, 1%) * only required when REG1=TPS73734 ** may be required to trim REG1 output voltage

1 68kΩ**	1 30kΩ**	1 1.8kΩ*	2 1.1kΩ	1 1kΩ*	1 330Ω	4 300Ω
1 150Ω	2 100Ω	1 82Ω	5 51Ω	2 33Ω (2012/0805 size)		

at around 3.328V, presumably due to resistor tolerances. We solved this by soldering a 30kΩ resistor across the top of the 1kΩ resistor, bringing the 3.4V rail up to 3.399V.

We've added 30kΩ and 68kΩ resistors to the parts list. If your 3.4V rail is below 3.34V, solder the 30kΩ resistor in parallel with the 1kΩ resistor, while if it's between 3.34V and 3.37V, use the 68kΩ resistor instead. Between 3.37V and 3.5V should be OK. An output from REG1 above 3.5V is unlikely.

If you use the fixed version of REG2 (TPS73734) its output should be between 3.36 and 3.44V so it should not require any trimming.

Assuming the voltages seem OK, the next step is to hook the output(s) of the prescaler up to your frequency counter or scope. If this device has an option

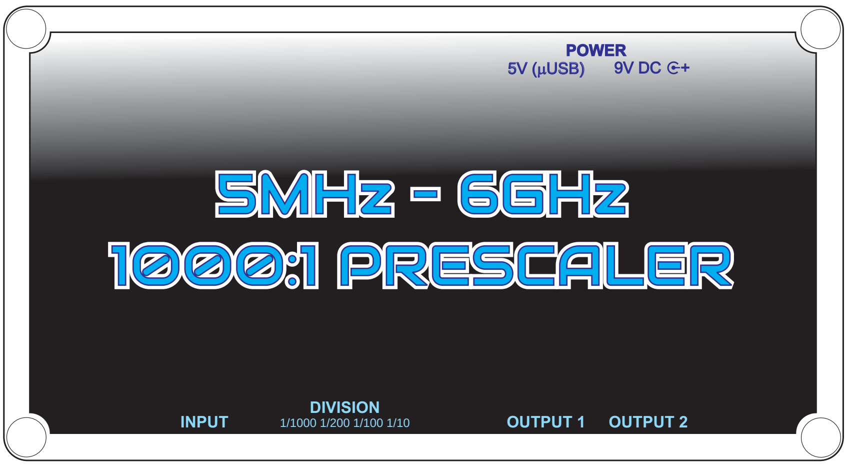


Fig.10: same-size artwork for the *RF Prescaler* front panel. There are no holes in the top panel to be drilled. We used only the inner portion of the artwork as you can see from our photos. You can photocopy this artwork without breaking copyright – or if you prefer, it can also be downloaded (as a PDF) from the *EPE* website.

for (or a fixed) 50Ω input impedance, select this. If your counter/scope only has a high impedance input, you will need to terminate the cable at its input using a 50Ω or 75Ω resistor.

Assuming this device has a BNC input, you can do this by connecting a BNC T adaptor to that input, with a termination plug on one end and the cable from the *RF Prescaler* on the other; see Fig.7.

You also need a signal source which can produce a signal of at least 5MHz (and ideally higher) into a 50Ω load. Connect this up to the *RF Prescaler's* input, power it up and check the reading from the output(s). Confirm that it is steady and in the expected range. Move switch S1 and check that the frequency reading is as expected on each setting; its left-most position is 1000:1 and right-most is 10:1.

Ensure that your signal generator can produce sufficient amplitude for correct operation, as shown in Fig.6, keeping in mind that the higher the frequency, the less signal you need for the *RF Prescaler* to operate. Note also that it will operate with signal levels a few dB below the sensitivity curve shown in Fig.6 with increasing jitter (and thus possibly decreasing accuracy in the reading) the further below the curve your signal is.

Putting it in a case

While we found the *RF Prescaler* operated reasonably well without a case, it's usually a good idea to shield RF equipment, both to prevent interference from affecting its operation and to prevent it from producing too much EMI which might affect other equipment.

Hence, our *RF Prescaler* is designed to fit in an inexpensive diecast aluminium case measuring 111 × 60 × 30mm (Jaycar HB5062). If you have a drill press and are reasonably experienced with machining aluminium, it should take you about one hour to install it in the case.

Start by printing out the drilling templates, shown in Fig.9 and also available for download as a PDF from the *EPE* website. Cut these out and glue/tape them onto the front and back of the case, centred as well as is possible.

Centre punch the holes and drill each one using a 3mm pilot hole. For the rectangular cut-out on the front panel, drill three 3mm holes inside the outline, one at either end and one in the centre.

The rectangular cut-out on the rear is only necessary if you're using a USB power supply. The rectangle shown is large enough to expose the microUSB connector; however, you will probably have to expand it considerably to get the plug to fit in. Alternative, if using a DC plugpack (as recommended), you can drill the adjacent hole instead.

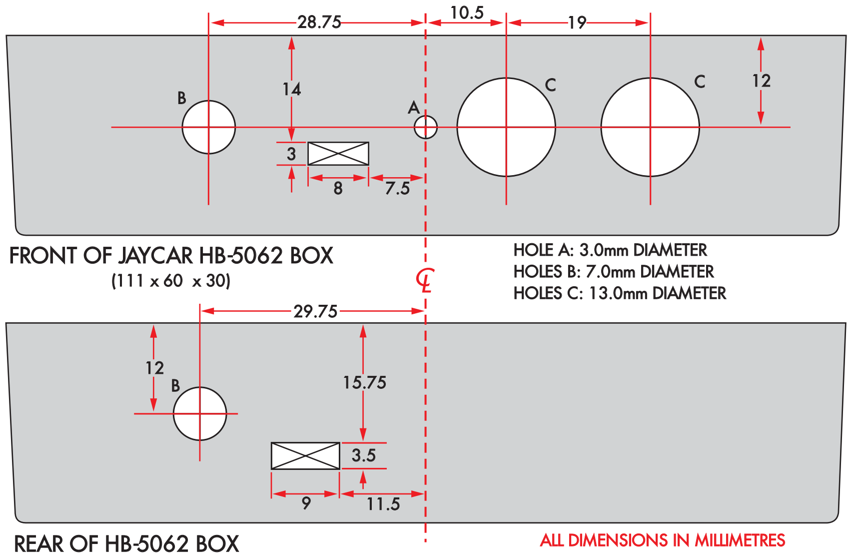


Fig.9: drilling detail for the diecast box. You don't need both the 7mm hole and the micro USB slot on the rear if you only intend to use one power source.

Once each pilot hole has been drilled, use either a stepped drill, series of larger drill bits or tapered reamer to enlarge each hole to its final size. File any rectangular cut-outs flat and then enlarge them to size.

Make sure each hole is clean (ie, no swarf) and get rid of all the aluminium shavings, then remove the nuts and washers from the BNC connectors and test fit the PCB in the case. You will need to angle it in. The front panel holes are slightly oversize to give you enough room to do so.

Don't force it in if it won't go in easily; if you do, you may not be able to get it out! Simply enlarge the holes slightly and it should pop in with only modest force and you can then drop it down to be parallel with the base. We suggest that you put switch S1 in one of the centre positions initially, then once the PCB is in the case, make sure the slot is wide enough to allow all four positions to be used.

Make sure that you check that the rear panel hole(s) are large enough to make a good power supply connection to the PCB. Most barrel plugs should be long enough to fit through the hole and into the connector. If yours isn't, you may need to cut it off and solder a longer one onto the plugpack.

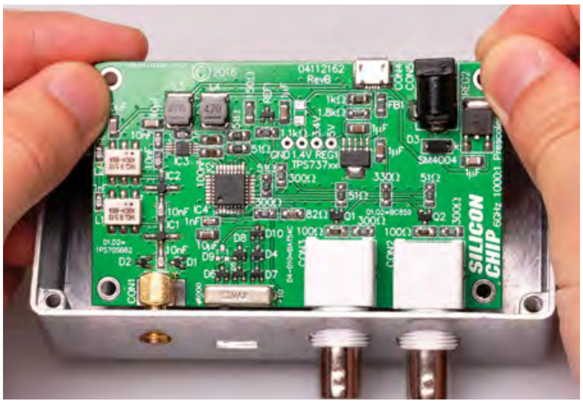
With the PCB in the case, you can now use it as a drilling template to drill four 3mm holes in the base. Remove the PCB by lifting the rear and then pulling it out, then clean out the aluminium dust.

Now, feed a 10mm machine screw up through one of the holes in the base and place two of the 1mm-thick nylon washers over its shaft, then screw on a nylon nut until the screw thread is just about poking through the nut. Repeat for the other three holes. If you're using screw-on rubber feet, you should pass the 10mm machine screws up through the feet before feeding them into the case.

If you lift the case up, the screws should drop down, leaving just the two nylon washers and nut sitting on the bottom of the case in each corner.

This should give you enough room to lever the PCB back in. Press down on one corner of the PCB and rotate that screw clockwise until its shaft is just poking through the PCB, then hold an M3 nut down on the shaft and continue tightening until the screw has gone all the way into the base and the nut is holding the PCB down.

Repeat for all four corners. You can now place the washers back over the BNC connectors and screw the nuts back on.



Fitting the completed PCB into the case is very much a 'shoehorn' affair, but it does fit! Don't force it – a bit of judicious 'jiggling' should get it in place.