

# Switching Diode Frequency Doublers

by  
Charles Wenzel

## Diode Selection

Ordinary fast switching silicon diodes, special fast recovery junction diodes, schottky barrier diodes, varactors and even old-fashioned germanium diodes or vacuum tubes may be used to construct signal powered frequency doublers.

The best choice is usually schottky barrier diodes which reliably exhibit low flicker noise and fast switching speeds in addition to a low barrier potential. Hybrid versions are available with a p-n guard ring which enhances the breakdown voltage but increases the junction capacitance to more than 1 pf. A common part is the 1N5711 which has a breakdown voltage of 70 volts and a junction capacity of 2 pf maximum. Passivated diodes constructed without the guard ring exhibit lower breakdown voltage but also have less junction capacity. A typical part is the 5082-2835 which has a breakdown voltage of only 8 volts with a junction capacity less than 1 pf.

Perhaps a second choice is a subset of "computer switching diodes" usually referred to as "ultra-fast" diodes exhibiting switching times under 1 nanosecond. The FD700 has a junction capacity of 1 pf and a  $t_{rr}$  of only 0.7 nanoseconds! And it can handle 250 ma forward and 30 volts reverse. Silicon junction diodes have a higher barrier potential than schottky diodes so the input impedance for a given circuit and signal level will be higher but with proper matching the silicon diodes will give more output for a given input level. In the past silicon diodes were avoided in low noise multiplier applications due to excessive flicker levels but modern silicon diodes exhibit performance similar to silicon schottky diodes. As with most low noise components, variations between manufacturers and even individual lots can be significant.

Ordinary computer diodes such as the 1N914 or the 1N4148 have a switching speed of 4 nanoseconds with a breakdown voltage of 100

volts. These diodes will give excellent results up to several hundred MHz for pennies.

Silicon Schottky Diodes		
P/N	Vbr	Capacitance
1N5711	70 volts	2.0 pf
1N5712	20 volts	1.2 pf
5082-2835	8 volts	1.0 pf
5082-2301	30 volts	1.0 pf
5082-2400	30 volts	0.7 pf
5082-2787	4 volts	0.12 pf
5082-2711	4 volts	0.1 pf

Silicon Switching Diodes		
P/N	Trr	Capacitance
1N914	4 ns	4.0 pf
1N4148	4 ns	4.0 pf
1N916	4 ns	2.0 pf
1N4149	4 ns	2.0 pf
1N4151	2 ns	4.0 pf
1N5282	2 ns	2.5 pf
1N4244	0.75 ns	0.8 pf
1N4376	0.75 ns	1.0 pf
FD700	0.70 ns	1.0 pf

Varactor diodes may be used in ordinary full-wave rectifier circuits to achieve a bit of wave shaping for enhanced conversion efficiency.

Germanium point-contact diodes have very low barrier potential and tube diodes have a warm glow but neither are practical for modern production.

## Circuits

Frequency doublers are commonly constructed from full-wave voltage rectifiers and have high conversion efficiency with good odd harmonic rejection. The higher even harmonics rapidly drop by the square of the harmonic number. In other words, the full-wave rectifier's waveform looks much like the desired second harmonic sinewave and filtering is relatively easy. Broadband frequency doublers available as pre-packaged modules feature proprietary transformers with excellent bandwidth but custom designs can usually exceed other performance specifications including conversion

loss, noise, harmonic content and often cost. Fig. 1 shows basic full-wave doubler configurations using ordinary transformers. The output transformer for the two diode doubler is single-ended and is often replaced by a choke to ground when no impedance transformation is needed (which is often the case).

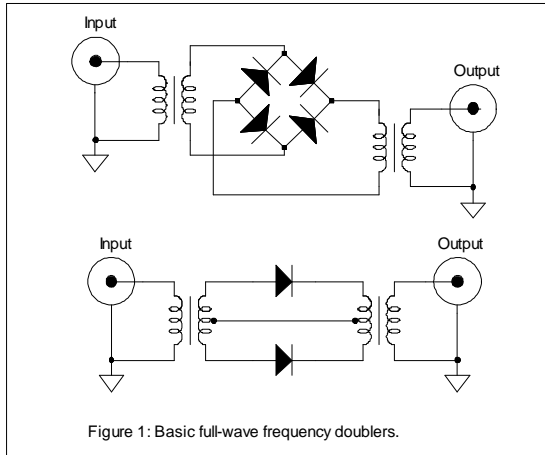


Figure 1: Basic full-wave frequency doublers.

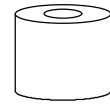
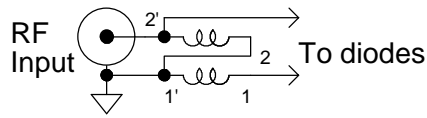
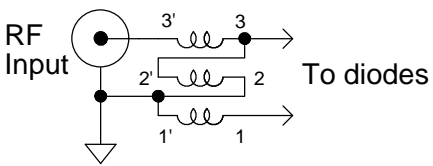
Good odd-harmonic rejection requires that the doubler respond equally to the positive and negative portions of the input sine wave. Although diode matching is a good idea, the biggest problem is usually an unbalanced input which results in one polarity receiving more signal than the other (usually due to capacitive coupling through the input transformer). The most common solution is to use a specially wound transformer called a **balun** which is short for "balanced to unbalanced" (fig. 2). Baluns avoid the inter-winding capacitance problem and are usually preferred to the simple transformers depicted in fig. 1. A less common but effective alternative is to place an electrostatic shield between the primary and secondary. However, shielded transformers are usually deemed too difficult to manufacture<sup>1</sup>.

<sup>1</sup>Although they are difficult to manufacture, shields also offer excellent common-mode isolation and may be worth the trouble when endeavoring to corral undesired spurious signals. A fairly effective shielded transformer may be constructed with a pot core by wrapping a copper foil shield between the primary and secondary making sure to insulate the ends from each other to prevent a shorted turn. Connect a ground wire from the midpoint of the foil to the nearest small-signal ground on the board. With a little care this simple shield will exhibit much less than 1 pf coupling from primary to secondary.

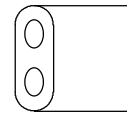
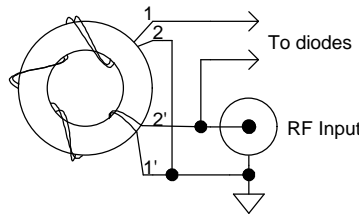
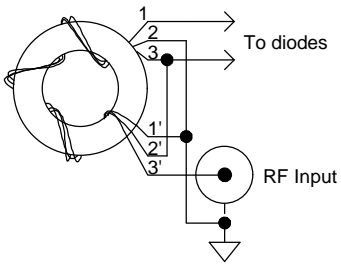
Ordinary ferrite beads make nice balun transformers and are widely used in packaged mixers and doublers. Beads are intended to slip over a single uninsulated conductor but they can be purchased with extra processing to remove sharp edges especially for transformers and multi-turn chokes wound with insulated wire. Choose a ferrite bead made from material suitable for the frequency range of interest but remember that the low frequency ferrites are often conductive.<sup>2</sup> Multi-hole cores allow the ends of the coils to be separated reducing winding capacity and increasing the bandwidth. The common two-hole balun has one-half of the windings passing through each hole. Pot cores are assembled from several pieces and are mechanically inconvenient unless a large number of turns is required. Gapped pot cores offer precision inductance and good saturation resistance. Toroid cores are quite popular and are readily available in many sizes and materials including lossy ferrite, high-Q ferrite, and various powdered metals. The powdered metal cores offer high stability and Q in tuned applications and exhibit low noise and good power handling characteristics. High-Q ferrites are not as stable and are subject to magnetization by weak fields: a refrigerator magnet can permanently devastate the Q and tuning of a high-Q ferrite tank. Lossy ferrites are most commonly used in broadband small-signal baluns.

Fig. 2 shows 1:1 and 1:4 baluns suitable for use with frequency doublers. The 1:1 balun is most likely to be used on the input when the source impedance is significantly higher than 50 ohms or in special cases where high drive power is desired. The 1:4 balun is commonly used for 50 or 75 ohm small-signal sources. Fig. 3 shows the performance of 2-diode doublers using different diode types and 1:4 baluns doubling 40 MHz to 80 MHz. The baluns are 4 turns wound on a two-hole core made from Fair-Rite No. 43 material with two turns through each hole wrapped back around the outside of the core. ("Turns" are the number of passes through the center of the core.) The 1:4 balun was selected to achieve sufficient

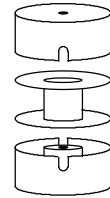
<sup>2</sup> Author's note: While a colleague and I were troubleshoot a prototype we noticed an eerie orange light coming from under the p.c.b. It turned out to be an orange-hot ferrite bead conducting current from the power supply wire directly to the ground plane!



Ferrite bead: Watch for sharp edges and conductive ferrite.



Two-hole balun: Wind around outside of one hole- then the other for maximum b.w. (min. winding capacity)



Pot cores make good baluns and shielded transformers. Gapped cores are usually tuned and ungapped cores made from lossy ferrite give high bandwidth.

A 1:4 balun provides twice the voltage to the diodes for a given input power and will exhibit a good return loss for lower level inputs.

A 1:1 balun shown wound on a toroid core using a twisted tri-filar winding. Twisting the wires and keeping the ends apart improves the high frequency performance. Multi-hole balun cores allow the turns to be physically separated even more for low capacitance and high bandwidth.

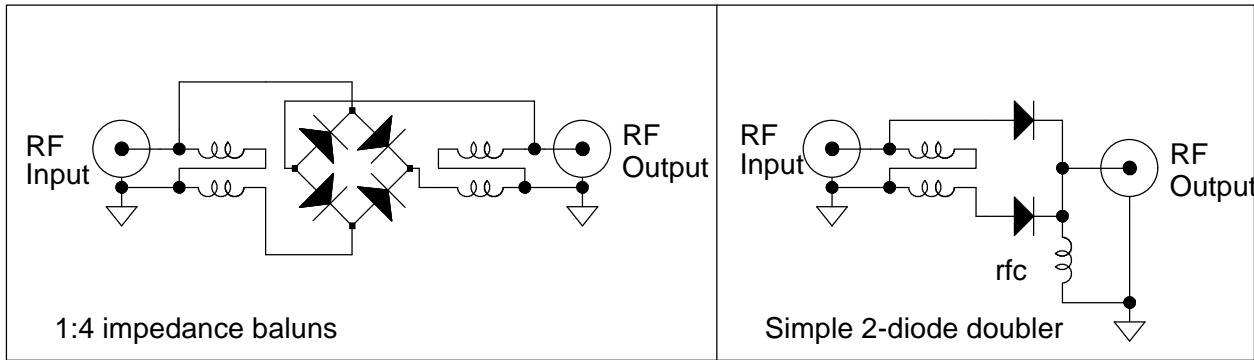


Figure 2: Baluns for frequency doublers.

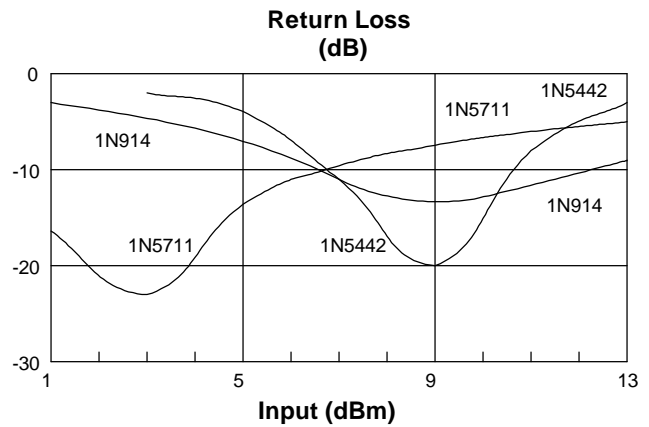
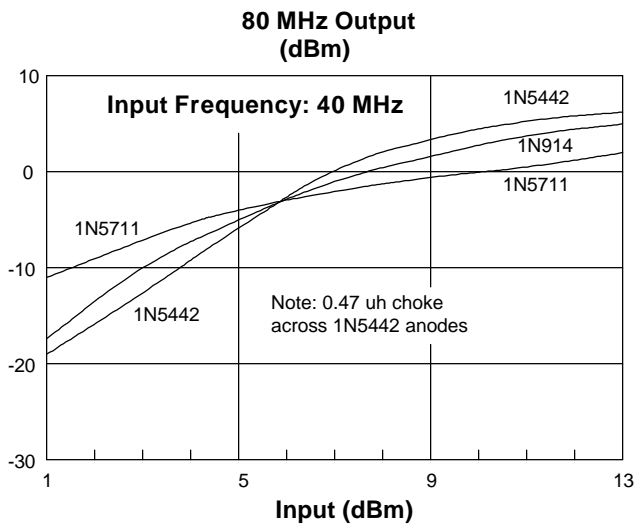


Figure 3: Two diode doubler output power and return loss.

diode voltage with input power levels appropriate for small-signal diodes and 4 turns is about right for input frequencies from 10 MHz to over 200 Mhz. The 2-diode output choke is not critical and several turns on the same type of core as the input balun is sufficient. Four diode doublers give similar results with the best return loss occurring at higher input levels.

The curves include the 1N5442 which is a varicap diode not normally used in this type of circuit. A 0.47 uH choke was connected across the anodes of the diodes to resonate the diode capacity at 40 Mhz so this doubler is somewhat tuned but the conversion efficiency is quite high with the output only 6 dB below the input for input levels near 10 dBm. Diode matching is difficult so the fundamental will be larger. Also, the return loss is good over a narrower input level range and the frequency response is limited. But if a couple of dB more output is desperately needed from a passive doubler this circuit might be the answer.